Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999

DRAFT STAFF REPORT

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Executive Summary

Senate Bill (SB) 1771, chaptered in September of 2000, requires the California Energy Commission, in consultation with other state agencies, to update the inventory of greenhouse gas emissions in California by January 1, 2002 and every five years thereafter. This report is the updated greenhouse gas inventory, which presents preliminary estimates of emissions from 1990 through 1999.

SB 1771 states that the Commission shall update greenhouse gas emission estimates "for all sources located in the state as identified in the Commission's 1998 report entitled *Appendix A: Historical and Forecasted Greenhouse Gas Emissions Inventories for California*." However, following publication of the 1998 inventory, the Intergovernmental Panel on Climate Change (IPCC) has adopted new guidelines on how to prepare national inventories by adding new emission source categories and improving some of the methods used to estimate emissions. This report follows the new IPCC guidelines and is consistent with the methods used to prepare the national inventory: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*. At the same time, this report makes use of California-specific data and methods when they result in better estimates of in-state emissions.

Gross greenhouse gas emissions in California increased approximately 1 percent from 425 million metric tons of carbon dioxide equivalent ($MMTCO_2$ Eq.) to 428 $MMTCO_2$ Eq. from 1990 to 1999. Carbon dioxide emissions from fossil fuel combustion accounted for the majority of emissions throughout the period (83 percent in 1999). Emissions from landfills and agricultural soil management were each responsible for roughly three percent of annual emissions and were responsible for the majority of state methane and nitrous oxide emissions, respectively. Substitution of ozone-depleting substances is the fastest growing source of emissions, increasing from 0.12 $MMTCO_2$ Eq. in 1990 to 7.00 $MMTCO_2$ Eq. in 1999. The dramatic increase in this sector was due to penetration of substitutes to ozone-depleting chemicals in the mid to late 1990s in response to the terms of the Montreal Protocol.

Changes in carbon from land-use change and forestry activities in California indicate that there was a net sequestration of carbon in California from this sector. However, sequestration in the state decreased from more than 25 $MMTCO_2$ Eq. in 1990 to slightly less than 19 $MMTCO_2$ Eq. in 1999, offsetting 6 and 4 percent of gross GHG emissions, respectively.

Net GHG emissions in California increased approximately 2 percent from 399 $MMTCO_2$ Eq. in 1990 to 409 $MMTCO_2$ Eq. in 1999. (See Table ES-1). Although emissions of GHGs are trending upward in California, the increases are far more gradual when compared to emissions from the U.S. as a whole. Gross and net emissions in California increased 1 percent and 2 percent over the ten-year period, respectively, as compared to 12 percent and 16 percent increases in national gross and net emissions during the same period.

**Table ES-1: Recent Trends in California Greenhouse Gas Emissions and Sinks (MMTCO$_2$ Eq.)**

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Carbon Dioxide (CO$_2$)	**363.76**	**350.47**	**342.79**	**338.56**	**355.64**	**346.17**	**346.83**	**348.19**	**355.49**	**362.82**
Fossil Fuel Combustion	358.16	345.27	337.80	333.51	350.00	340.39	340.87	342.09	349.33	356.28
Cement Production	4.62	4.26	4.07	4.18	4.75	4.81	4.97	5.12	5.19	5.55
Other	0.97	0.93	0.92	0.87	0.89	0.97	0.99	0.98	0.98	1.00
Soils and Forests (Sink)	-25.58	-25.21	-20.97	-20.68	-20.29	-19.88	-19.61	-19.26	-19.13	-18.79
Methane (CH$_4$)	**34.63**	**34.87**	**35.47**	**34.35**	**34.84**	**34.79**	**32.75**	**32.17**	**29.99**	**31.65**
Landfills	16.95	17.02	17.26	17.32	17.06	16.58	15.09	14.24	12.27	13.17
Enteric Fermentation	7.53	7.25	7.37	6.59	7.14	7.25	6.77	6.88	6.84	7.08
Manure Management	3.29	3.87	3.93	4.03	4.30	4.55	4.55	4.88	4.80	5.21
Natural Gas System	3.34	3.24	3.19	3.05	2.94	3.00	2.91	2.91	2.87	2.90
Other	3.52	3.50	3.72	3.36	3.41	3.40	3.42	3.26	3.22	3.29
Nitrous Oxide (N$_2$O)	**24.60**	**23.09**	**23.52**	**24.41**	**23.56**	**25.40**	**24.57**	**23.00**	**23.28**	**23.55**
Agricultural Soils	14.93	13.35	13.68	14.69	14.04	15.93	15.51	14.10	14.45	14.74
Mobile Source Combustion	6.82	7.06	7.15	7.14	7.02	6.81	6.63	6.39	6.32	6.24
Other	2.85	2.69	2.70	2.57	2.50	2.67	2.43	2.51	2.51	2.57
HFCs, PFCs, and SF$_6$	**2.07**	**2.09**	**2.29**	**2.84**	**3.54**	**5.43**	**6.81**	**7.87**	**8.73**	**9.70**
Gross Emissions	**425.05**	**410.52**	**404.08**	**400.16**	**417.59**	**411.79**	**410.95**	**411.23**	**417.49**	**427.72**
Total Sinks	*-25.58*	*-25.21*	*-20.97*	*-20.68*	*-20.29*	*-19.88*	*-19.61*	*-19.26*	*-19.13*	*-18.79*
Net Emissions	**399.47**	**385.31**	**383.11**	**379.48**	**397.30**	**391.91**	**391.34**	**391.97**	**398.37**	**408.93**

Note: Totals may not add due to rounding.

Carbon dioxide dominated the emission profile in California throughout the ten-year period, accounting for 85 percent of gross emissions in 1999. Methane and nitrous oxide emissions accounted for approximately 7 and 6 percent of gross 1999 emissions, respectively. Emissions of hydrofluorocarbons (HFCs), perfluorocarbons, (PFCs) and sulfur hexafluoride (SF$_6$) accounted for the remaining 2 percent of gross 1999 emissions. The contribution of these gases to gross emissions from 1990 through 1999 is shown graphically in Figure ES-1.

Carbon dioxide emissions from the combustion of fossil fuels in California have remained at about the same levels since the mid-1970s. In part, air quality and energy standards, regulations, and policies explain this trend. Without the reductions attributable to them, emissions in the 1990s would have been about 20 percent higher. Another factor for this trend is the increase in imports of out-of-state electricity. If in-state sources had provided the energy generated by out-of-state power plants serving California, emissions from the combustion of fossil fuels in the 1990s would have been 5 to 11 percent higher than their historical levels. Under this scenario, however, in-state emissions would have remained almost at the same level from 1990 to 1999 because the amount of net electricity imports has remained more or less unchanged since 1983.

Figure ES-1: Emissions by Greenhouse Gas: 1990-1999
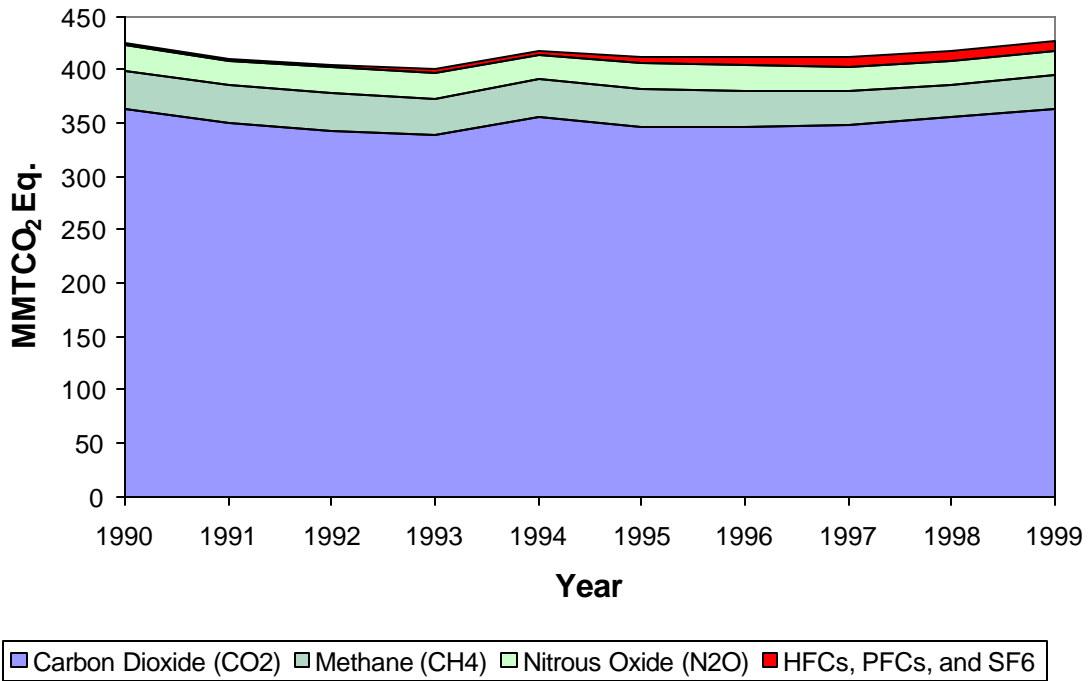
This study meets the requirements of the California Legislature. However, the Commission plans to further refine the state greenhouse gas emission estimates. The refined inventory will rely on improved data and methodologies planned and under development, it will include estimates of greenhouse gas emissions through the year 2000, a discussion of the uncertainty in estimates of emissions from key sources, and estimates for several sources not currently in the inventory.

Chapter 1

Overview

The potential risks of climate change have led over 180 nations, including the United States, to ratify the United Nations Framework Convention on Climate Change (UNFCCC), a landmark agreement to reduce the threat of climate change. In ratifying the framework, nations agree to certain reporting requirements. In particular, each nation is required to prepare and periodically report on: (1) the magnitude and sources of greenhouse gas (GHG) emissions and sinks, (2) any ongoing activities to reduce emissions and enhance sinks, and (3) other activities related to adaptation, research, and education. Under the UNFCCC, national inventories are to be based on the methodologies and reporting structure of the Intergovernmental Panel on Climate Change (IPCC), and are to include estimates of emissions of six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

In California, Senate Bill 1771, chaptered in September of 2000, requires the California Energy Commission, in consultation with other state agencies, to update the greenhouse gas emission estimates "for all sources located in the state as identified in the Commission's 1998 report entitled *Appendix A: Historical and Forecasted Greenhouse Gas Emissions Inventories for California*." Since the 1998 inventory was prepared the IPCC has however, adopted new guidelines for preparing national inventories. In particular, IPCC has added new source categories and developed improved methods for estimating emissions. The 2002 California GHG emissions inventory follows the new IPCC guidelines and is consistent with the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*. At the same time, this report makes use of California-specific data and methods when they result in better estimates of in-state emissions.

The scope of the *Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999* can be described as follows:

- **Statewide**: The inventory includes estimates of emissions across the state of California.

- **Sectors**: The inventory estimates emissions from five major sectors – Energy, Industrial Processes, Agriculture, Forestry, and Waste.

- **Thirty GHG Sources**: The inventory provides emissions from thirty sources of emissions and sinks. There are several sources for which data were not available at the state level; however, estimates of emissions from some of these sources may be included in subsequent inventories as data becomes available.

- **Six GHGs** : The inventory captures emissions of six greenhouse gases: CO_2, CH_4, N_2O, PFCs, HFCs, and SF_6. These six greenhouse gases were chosen because they are required in national inventories prepared under the UNFCCC.

- **Time Series:** The inventory includes emissions over a ten-year period, starting in 1990 and ending in 1999. Due to data constraints, estimates for 2000 were not included in the inventory.

The methods used to develop estimates for this inventory are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* and with the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*. Where possible, data from state agencies were used to develop emission estimates. In cases where state agencies were unable to provide the necessary data, state-level data was used that is collected and reported at a national level.

While this study meets the requirements of the California Legislature, due to time constraints and data availability, the Commission plans to further refine state greenhouse gas emission estimates. This revised inventory when completed will rely on improved data and methodologies planned and under development, will include estimates of greenhouse gas emissions through the year 2000, a discussion of the uncertainty in estimates of emissions from key sources, and estimates for sources not currently in the inventory. .

Scientific and Technical Aspects of Global Climate Change

Climate change refers to long-term fluctuations in the climate system including, but not limited to, changes in temperature, precipitation, and wind. Changes in climate are driven by changes in the amount of radiation present in the Earth's atmosphere. The Earth's surface absorbs radiation from the Sun and this energy is then redistributed by the atmospheric and oceanic circulations and radiated back to space. In general, incoming solar radiation is approximately balanced by outgoing terrestrial radiation. Any factor altering the distribution of radiative energy is likely to affect climate. According to the IPCC Third Assessment Report, radiative forcing describes a change to the net radiative energy available to the global Earth-atmosphere system. Radiative forcing may be positive – warming the Earth's surface and lower atmosphere – or negative – cooling the Earth's surface and lower atmosphere.

Increased concentrations of greenhouse gases inhibit the Earth's ability to radiate energy back to space. Greenhouse gases in the Earth's atmosphere absorb outgoing terrestrial radiation, causing less heat to escape and creating an enhanced greenhouse effect. The greenhouse effect has taken place for billions of years, due to the presence of naturally occurring greenhouse gases in the Earth's atmosphere. However, over the last fifty years, anthropogenic greenhouse gas emissions (i.e., human-induced emissions) are believed to be responsible for most of the observed warming.

Naturally occurring greenhouses gases, such as water vapor, CO_2, CH_4, N_2O, and ozone (O_3), are emitted as part of the Earth's hydrological, geological, and biological cycles. Certain synthetic compounds, including chlorofluorocarbons (CFCs), HFCs, partially halogenated chlorofluorocarbons (HCFCs), SF_6, and PFCs, can also behave as greenhouse gases. Additionally, gases referred to as "ozone precursors" can indirectly influence the formation and destruction of ozone, which itself has a direct radiative force. Carbon monoxide (CO), oxides of nitrogen (NO_x), and nonmethane volatile organic compounds (NMVOCs) are such indirect contributors to the greenhouse effect.

The aforementioned greenhouse gases have different effects on the Earth's radiative energy balance. To allow scientists to normalize the effects of emissions of the different gases, the IPCC created the concept of Global Warming Potential (GWP) to compare the abilities of greenhouse gases to trap heat in the atmosphere relative to a

reference gas, carbon dioxide. The GWP is measured as the ratio of the radiative forcing of one unit mass of a gas relative to that capability of one unit mass of carbon dioxide over a time period. The time period recommended by the IPCC and the United States is the 100-year time horizon; thus, this study uses 100-year GWPs, listed in Table 1-1.

Table 1-1: Global Warming Potential for Greenhouse Gases

Gas	100-Year GWP
CO_2	1
CH_4	21
N_2O	310
HFC-143a	1,300
HFC-23	11,700
HFC-152a	140
SF_6	23,900

Source: EPA 2001

Greenhouse gas emissions can be expressed either on a mass basis of the gas (for example, 1 million metric tonne of methane), or normalized by weighting the emissions by the GWP of the gas (continuing the example, 21 million metric tonnes of carbon dioxide, which has an equivalent radiative forcing). In the remainder of this report, we use units of million metric tonnes of carbon dioxide equivalent ($MMTCO_2$ Eq.).

Recent Trends in California Greenhouse Gas Emissions

Gross greenhouse gas emissions in California increased from 425 $MMTCO_2$ Eq. to 428 $MMTCO_2$ Eq. from 1990 to 1999. Carbon dioxide emissions from fossil fuel combustion consistently accounted for the majority of emissions (83 percent in 1999). Emissions from landfills and agricultural soil management were each responsible for roughly 3 percent of annual emissions and were responsible for the majority of state methane and nitrous oxide emissions, respectively. Substitution of ozone-depleting substances was the fastest growing source of emissions, increasing from 0.12 $MMTCO_2$ Eq. in 1990 to 7.00 $MMTCO_2$ Eq. in 1999. The dramatic increase in emissions from this sector was due to market penetration of substitutes to ozone-depleting chemicals in the mid- to late-1990s in response to the terms of the Montreal Protocol.

Changes in carbon from land-use change and forestry activities in California indicate that there was a net carbon sequestration from this sector. However, sequestration in the state decreased from more than 25 $MMTCO_2$ Eq. in 1990 to slightly less than 19 $MMTCO_2$ Eq. in 1999, offsetting 6 and 4 percent of gross GHG emissions, respectively.

Net GHG emissions in California increased approximately 2 percent from 399 $MMTCO_2$ Eq. in 1990 to 409 $MMTCO_2$ Eq. in 1999, as compared to a 16 percent increase in national emissions during the same period. Table 1-2 presents emissions by gas and by source for the ten-year period.

Carbon dioxide dominated the emission profile in California throughout the ten-year period, accounting for 85 percent of gross emissions in 1999 (see Table 1-2). Methane and nitrous oxide emissions accounted for approximately 7 and 6 percent of gross 1999 emissions, respectively. Emissions of HFCs, PFCs and SF_6 accounted for the remaining 2 percent of gross 1999 emissions. The contribution of these gases to gross emissions from 1990 through 1999 is shown graphically in Figure 1-1.

Table 1-2: California Greenhouse Gas Emissions and Sinks: 1990-1999 (MMTCO$_2$ Eq.).
Note: emission totals in the "Carbon Dioxide" row exclude soils and forests.

|	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Carbon Dioxide (CO$_2$)	**363.76**	**350.47**	**342.79**	**338.56**	**355.64**	**346.17**	**346.83**	**348.19**	**355.49**	**362.82**
Fossil Fuel Combustion	358.16	345.27	337.80	333.51	350.00	340.39	340.87	342.09	349.33	356.28
Cement Production	4.62	4.26	4.07	4.18	4.75	4.81	4.97	5.12	5.19	5.55
Lime Production	0.25	0.22	0.20	0.15	0.16	0.18	0.16	0.16	0.15	0.14
Limestone and Dolomite Consumption	0.14	0.13	0.12	0.11	0.12	0.16	0.18	0.18	0.19	0.20
Soda Ash Production and Consumption	0.22	0.21	0.21	0.21	0.21	0.22	0.21	0.22	0.22	0.21
Carbon Dioxide Consumption	0.07	0.08	0.08	0.08	0.08	0.09	0.11	0.12	0.12	0.13
Waste Combustion	0.30	0.30	0.31	0.31	0.32	0.32	0.32	0.31	0.30	0.31
Soils and Forests (Sink)	-25.58	-25.21	-20.97	-20.68	-20.29	-19.88	-19.61	-19.26	-19.13	-18.79
Methane (CH$_4$)	**34.63**	**34.87**	**35.47**	**34.35**	**34.84**	**34.79**	**32.75**	**32.17**	**29.99**	**31.65**
Oil System	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.38	0.38	0.36
Natural Gas System	3.34	3.24	3.19	3.05	2.94	3.00	2.91	2.91	2.87	2.90
Coal Mining	0.18	0.19	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Landfills	16.95	17.02	17.26	17.32	17.06	16.58	15.09	14.24	12.27	13.17
Enteric Fermentation	7.53	7.25	7.37	6.59	7.14	7.25	6.77	6.88	6.84	7.08
Manure Management	3.29	3.87	3.93	4.03	4.30	4.55	4.55	4.88	4.80	5.21
Flooded Rice Fields	0.41	0.36	0.41	0.45	0.50	0.48	0.52	0.54	0.50	0.52
Burning Agricultural Residues	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Wastewater	1.27	1.28	1.30	1.32	1.33	1.33	1.34	1.36	1.37	1.39
Mobile Source Combustion	0.54	0.52	0.51	0.49	0.48	0.46	0.44	0.43	0.42	0.41
Stationary Source Combustion	0.69	0.71	0.73	0.67	0.67	0.69	0.69	0.52	0.52	0.56
Nitrous Oxide (N$_2$O)	**24.60**	**23.09**	**23.52**	**24.41**	**23.56**	**25.40**	**24.57**	**23.00**	**23.28**	**23.55**
Nitric Acid Production	0.53	0.52	0.56	0.38	0.38	0.49	0.30	0.30	0.28	0.28
Waste Combustion	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Agricultural Soils	14.93	13.35	13.68	14.69	14.04	15.93	15.51	14.10	14.45	14.74
Manure Management	0.81	0.76	0.74	0.72	0.70	0.72	0.70	0.70	0.70	0.71
Burning Agricultural Residues	0.09	0.08	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.12
Human Sewage	0.93	0.87	0.85	0.94	0.86	0.93	0.91	1.00	1.04	1.05
Mobile Source Combustion	6.82	7.06	7.15	7.14	7.02	6.81	6.63	6.39	6.32	6.24
Stationary Source Combustion	0.46	0.43	0.44	0.41	0.42	0.40	0.39	0.36	0.35	0.39
HFCs, PFCs, and SF$_6$	**2.07**	**2.09**	**2.29**	**2.84**	**3.54**	**5.43**	**6.81**	**7.87**	**8.73**	**9.70**
Substitution of Ozone Depleting Substances	0.12	0.10	0.19	0.65	1.23	2.94	4.15	5.15	6.10	7.00
Semiconductor Manufacture	0.36	0.36	0.36	0.46	0.52	0.67	0.86	0.86	0.84	0.84
Electric Utilities	1.60	1.63	1.74	1.74	1.80	1.81	1.81	1.87	1.80	1.87
Gross Emissions	**425.05**	**410.52**	**404.08**	**400.16**	**417.59**	**411.79**	**410.95**	**411.23**	**417.49**	**427.72**
Total Sinks	*-25.58*	*-25.21*	*-20.97*	*-20.68*	*-20.29*	*-19.88*	*-19.61*	*-19.26*	*-19.13*	*-18.79*
Net Emissions	**399.47**	**385.31**	**383.11**	**379.48**	**397.30**	**391.91**	**391.34**	**391.97**	**398.37**	**408.93**

Chapter 7 of this report provides a comparison and historical trends of anthropogenic emissions relative to emissions from natural sources. In California, anthropogenic sources of both nitrous oxide and methane exceed the emissions from natural sources (e.g., wetlands and natural soils).

Carbon dioxide emissions in California have remained at about the same levels since the mid-1970s, despite significant increases in population and gross state product. This is in marked contrast to significant GHG emission increases in the United States as a whole. California's standards, regulations, and policies in the air quality and energy sectors are responsible for restraining the growth in GHG emissions; without them emissions in the 1990s would have been about 20 percent higher. In addition, in the early part of this period (up to about 1983), California increased its imports of electricity from other states. If in-state sources had provided the energy generated by out-of-state power plants serving California, emissions in the 1990s would have been about 5 to 11 percent higher than actual levels. Under this scenario, however, in-state emissions would have remained almost at the same level from 1990 to 1999 because the amount of net electricity imports has remained more or less unchanged since 1983.

Emissions and Sinks by Gas

The remainder of this chapter includes summaries of emissions by gas, beginning with CO_2. As shown in Figure 1-1, CO_2 dominated the emission profile in California over the entire period from 1990 through 1999. This is consistent with trends in other states and the United States as a whole.

Figure 1-1: Emissions by Greenhouse Gas: 1990-1999
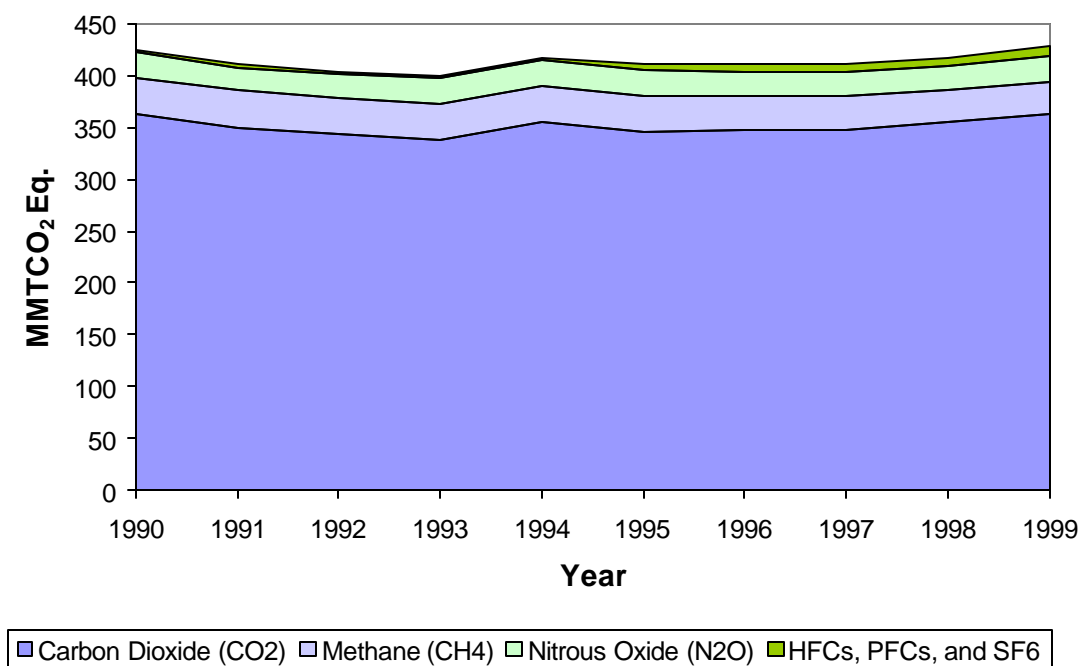
Carbon Dioxide Emissions and Sinks

Carbon is naturally cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. Some of the largest carbon fluxes occur between the atmospheric and land biotic reservoirs. In the atmosphere, carbon generally exists in its oxidized form – as CO_2.

Increased CO_2 concentrations in the atmosphere have been primarily linked to increased combustion of fossil fuels. Fossil fuel combustion in California accounted for 98 percent of gross California CO_2 emissions (see Table 1-3). Other sources of CO_2 emissions in California include non-energy production processes, land-use change and forestry practices, and waste combustion (See Figure 1-2). Carbon sinks in California offset roughly 5 percent of gross state CO_2 emissions.

Table 1-3: CO_2 Emissions: 1990-1999 (MMTCO$_2$ Eq.)

Sector/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Energy	**358.16**	**345.27**	**337.80**	**333.51**	**350.00**	**340.39**	**340.87**	**342.09**	**349.33**	**356.28**
Fossil Fuel Combustion	358.16	345.27	337.80	333.51	350.00	340.39	340.87	342.09	349.33	356.28
Industrial Processes	**5.30**	**4.90**	**4.69**	**4.74**	**5.32**	**5.46**	**5.64**	**5.79**	**5.86**	**6.24**
Cement Production	4.62	4.26	4.07	4.18	4.75	4.81	4.97	5.12	5.19	5.55
Lime Production	0.25	0.22	0.20	0.15	0.16	0.18	0.16	0.16	0.15	0.14
Limestone and Dolomite Consumption	0.14	0.13	0.12	0.11	0.12	0.16	0.18	0.18	0.19	0.20
Soda Ash Production and Consumption	0.22	0.21	0.21	0.21	0.21	0.22	0.21	0.22	0.22	0.21
Carbon Dioxide Consumption	0.07	0.08	0.08	0.08	0.08	0.09	0.11	0.12	0.12	0.13
Land-Use Change and Forestry	**-25.58**	**-25.21**	**-20.97**	**-20.68**	**-20.29**	**-19.88**	**-19.61**	**-19.26**	**-19.13**	**-18.79**
Forests and Soils	-10.10	-10.07	-9.72	-9.75	-9.67	-9.55	-9.55	-9.47	-9.58	-9.50
Harvested Wood	-15.49	-15.14	-11.25	-10.93	-10.62	-10.33	-10.05	-9.78	-9.55	-9.30
Waste	**0.30**	**0.30**	**0.31**	**0.31**	**0.32**	**0.32**	**0.32**	**0.31**	**0.30**	**0.31**
Waste Combustion	0.30	0.30	0.31	0.31	0.32	0.32	0.32	0.31	0.30	0.31
Gross Total	**363.76**	**350.47**	**342.79**	**338.56**	**355.64**	**346.17**	**346.83**	**348.19**	**355.49**	**362.82**
Net Total	**338.18**	**325.26**	**321.83**	**317.88**	**335.35**	**326.29**	**327.22**	**328.93**	**336.37**	**344.03**

Note: Totals may not sum due to independent rounding.

Figure 1-2: 1999 CO$_2$ Emissions in California by Sector
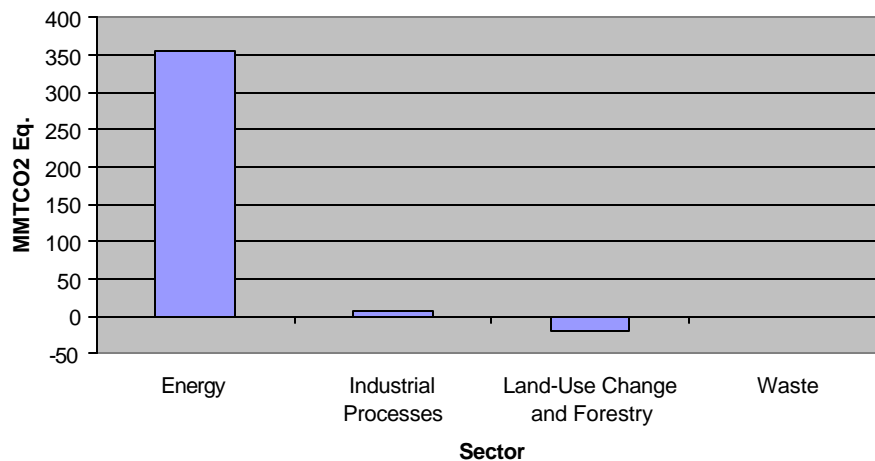
Energy

Following the IPCC guidelines, GHG emissions from energy-related activities include emissions from fuel combustion; and emissions released during the production, transmission, storage, and distribution of fuels. For example, nitrous oxide emissions from wood combustion in industrial boilers to produce steam are included in the energy sector.

Total CO$_2$ emissions from fossil fuel combustion in California in 1999 were 356.3 MMTCO$_2$ Eq., which accounts for approximately 6 percent of the U.S. emissions from this source. As seen in Table 1-3, total emissions from fossil fuel combustion were at their highest in 1990, underwent a rise and fall in 1994 and 1995, respectively, and then rose again from 1996 through 1999. Carbon dioxide emissions from petroleum accounted for the majority (about 67 percent) of total CO$_2$ emissions from fossil fuel combustion in California (see Figure 1-3). Consumption of petroleum occurred mostly in the industrial and transportation sectors, while over half of the natural gas consumed was in the industrial sector. Natural gas consumption in the industrial sector increased approximately 97 percent from 1990. Emissions from coal in the electric power and in other sectors were minor, especially compared to the rest of the United States.

The transportation sector accounted for the largest portion of emissions, averaging 59 percent of the total CO$_2$ emissions from fossil fuel combustion in California between 1990 and 1999. Transportation fossil fuel combustion did not fluctuate significantly during the 1990s, remaining around 200 MMTCO$_2$ Eq. Petroleum products accounted for nearly all of the consumption in this sector.

Energy use in the industrial sector ranked second to transportation in terms of total CO$_2$ emissions from fossil fuel combustion in California (about 26 percent in 1999). Emissions from the residential and commercial sectors accounted for 9 and 4 percent of total emissions from fossil fuel combustion in 1999, respectively.

Electric Utilities accounted for roughly 2 percent of CO$_2$ emissions from fossil fuel combustion in 1999. Carbon dioxide emissions from the electric utilities dropped 73 percent from 28.5 MMTCO$_2$ Eq. in 1990 to 7.7 MMTCO$_2$ Eq. by 1999. This is because by 1999 non-utility companies had purchased a significant fraction of the power plants

that used to belong to electric utilities. Emissions from non-utility electricity generation are currently included in the industrial sector. Emissions from utility and non-utility power plants accounted for about 16 percent of the in-state CO_2 emissions from the combustion of fossil fuels

Figure 1-3: 1999 CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector

Electric Utiliites
2%

Industrial
26%

Commercial
4%

Residential
9%

Transportation
59%
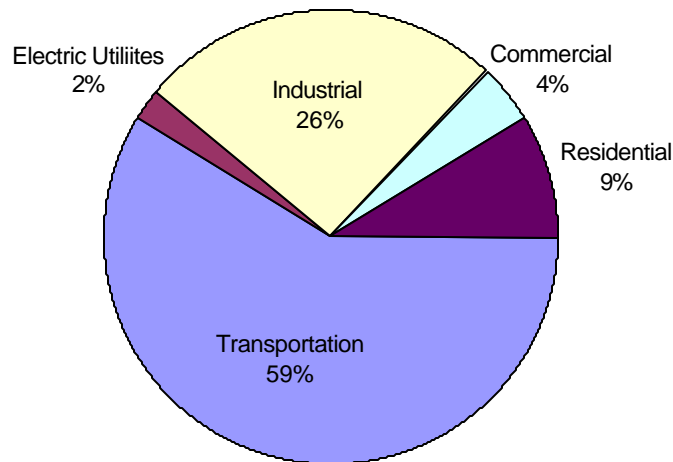
Industrial Processes

Carbon dioxide emissions from industrial processes in 1999 were 6.2 MMTCO$_2$ Eq. The majority of these emissions, nearly 90 percent, were generated from the cement production sector (see Figure 1-4). Other industrial sources of CO_2 emissions included lime production, limestone and dolomite consumption, soda ash consumption, and carbon dioxide manufacture.

Electricity Generation Sector

For this report, the electricity generation sector is composed of both utility and non-utility generation. NOTE: this section will be added by December 17, 2002.

Figure 1-4: 1999 CO$_2$ Emissions from Industrial Processes by Source

Cement Production
90%

Lime Production
2%

Limestone and
Dolomite
Consumption
3%

Soda Ash
Consumption
3%

Carbon Dioxide
Consumption
2%
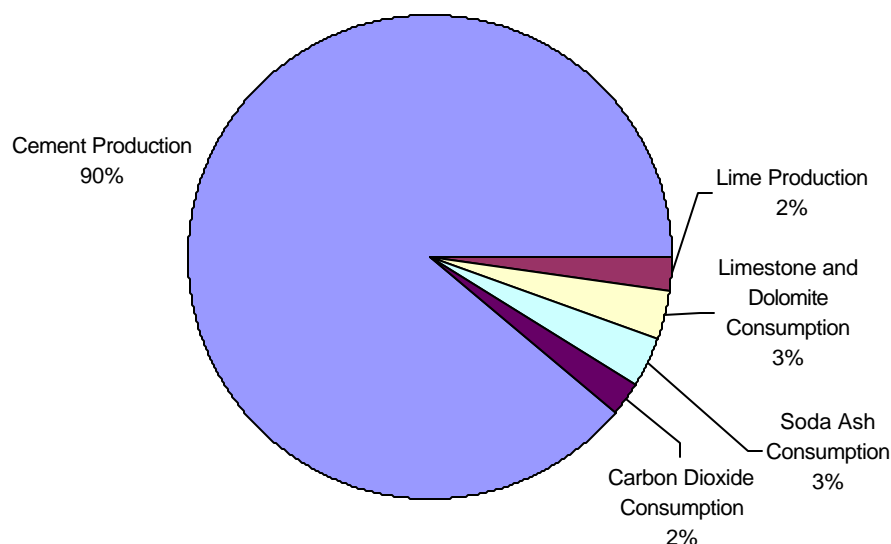
Land-Use Change and Forestry

Estimates of emissions and sinks from land-use change and forestry include (1) changes in forest carbon stocks; (2) changes in agricultural soil carbon stocks, and (3) changes in yard trimming carbon stocks in landfills. Estimated total annual net CO$_2$ flux from land-use change and forestry in 1999 was 18.8 MMTCO$_2$ Eq. (see Table 1-4). Sequestration offset 7 percent and 5 percent of gross state CO$_2$ emissions in 1990 and 1999, respectively. Over the ten-year period from 1990 to 1999, net sequestration decreased by 27 percent. This decline is primarily due to decreased carbon storage in wood products and landfilled wood.

Table 1-4: Net Carbon Flux From Land-Use Change and Forestry (MMTCO$_2$ Eq.)

Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Forests and Soils	**-10.10**	**-10.07**	**-9.72**	**-9.75**	**-9.67**	**-9.55**	**-9.55**	**-9.47**	**-9.58**	**-9.50**
Biomass	-18.48	-18.48	-18.66	-18.66	-18.66	-18.66	-18.66	-18.66	-18.66	-18.66
Forest Floor and Coarse Woody Debris	5.21	5.21	5.79	5.79	5.79	5.79	5.79	5.79	5.79	5.79
Soil	3.12	3.12	3.04	3.04	3.04	3.04	3.04	3.04	3.04	3.04
Liming of Ag Soils	0.06	0.09	0.11	0.07	0.16	0.27	0.27	0.35	0.25	0.33
Harvested Wood	**-15.49**	**-15.14**	**-11.25**	**-10.93**	**-10.62**	**-10.33**	**-10.05**	**-9.78**	**-9.55**	**-9.30**
Wood Products and Landfilled Wood	-11.00	-11.00	-7.44	-7.44	-7.44	-7.44	-7.44	-7.44	-7.44	-7.44
Landfilled Yard Trimmings	-4.49	-4.14	-3.81	-3.49	-3.18	-2.89	-2.61	-2.34	-2.11	-1.85
Total Net Flux	**-25.58**	**-25.21**	**-20.97**	**-20.68**	**-20.29**	**-19.88**	**-19.61**	**-19.26**	**-19.13**	**-18.79**

Note: Negative value indicates net sequestration. Totals may not add due to rounding.

Overall, California's forests were a net sink of CO$_2$, indicating that forest growth has been occurring at a faster pace than forest clearing, harvests, and decomposition. Net

negative fluxes – sequestration – in forests and soils were complemented by carbon storage in harvested wood products and landfills. (See Figure 1-5.)

Figure 1-5: 1999 CO$_2$ Emissions from Land-Use Change and Forestry by Source
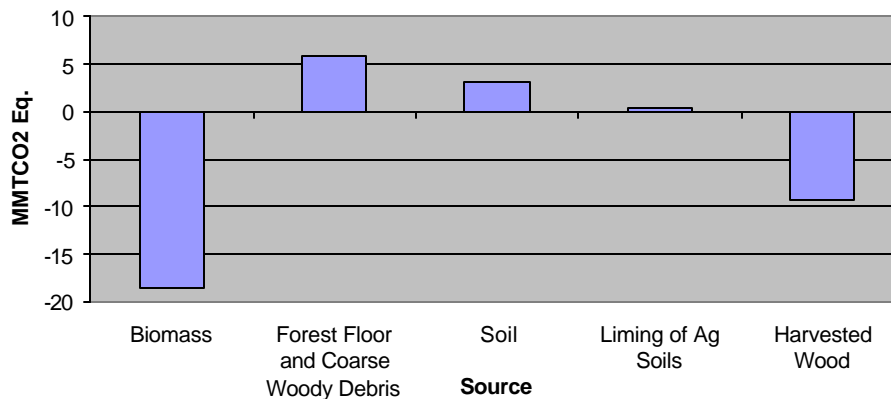
Note: Harvested wood includes wood products and landfilled wood and landfilled yard trimmings.

Waste

During combustion of municipal solid waste (MSW), organic materials are converted to CO$_2$. Carbon dioxide emitted from combustion of organic wastes that are of biogenic origin (i.e., paper, food scraps, yard trimmings) is considered part of the natural carbon cycle. Therefore, these emissions are excluded from this report.

Carbon dioxide emissions from combustion of non-biogenic wastes were essentially constant, starting the decade at 0.30 MMTCO$_2$ Eq. in 1990 and ending at 0.31 MMTCO$_2$ Eq. in 1999. In 1999, these emissions accounted for approximately 0.08 percent of gross state CO$_2$ emissions.

Methane Emissions

Methane accounted for more than 7 percent of gross 1999 emissions in California, down from 8 percent of gross emissions in 1990. Emissions by sector and source category are shown in Table 1-5.

Table 1-5: CH$_4$ Emissions: 1990-1999 (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Energy	**5.15**	**5.06**	**5.16**	**4.60**	**4.47**	**4.54**	**4.44**	**4.24**	**4.18**	**4.23**
Petroleum Systems	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.38	0.38	0.36
Natural Gas Systems	3.34	3.24	3.19	3.05	2.94	3.00	2.91	2.91	2.87	2.90
Coal Mining	0.18	0.19	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile Source Combustion	0.54	0.52	0.51	0.49	0.48	0.46	0.44	0.43	0.42	0.41
Stationary Source Combustion	0.69	0.71	0.73	0.67	0.67	0.69	0.69	0.52	0.52	0.56
Agriculture	**11.26**	**11.51**	**11.74**	**11.11**	**11.98**	**12.33**	**11.87**	**12.34**	**12.17**	**12.85**
Enteric Fermentation	7.53	7.25	7.37	6.59	7.14	7.25	6.77	6.88	6.84	7.08
Manure Management	3.29	3.87	3.93	4.03	4.30	4.55	4.55	4.88	4.80	5.21
Flooded Rice Fields	0.41	0.36	0.41	0.45	0.50	0.48	0.52	0.54	0.50	0.52
Burning Agricultural Residues	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Waste	**18.21**	**18.30**	**18.57**	**18.64**	**18.39**	**17.92**	**16.43**	**15.60**	**13.64**	**14.56**
Landfills	16.95	17.02	17.26	17.32	17.06	16.58	15.09	14.24	12.27	13.17
Wastewater Treatment	1.27	1.28	1.30	1.32	1.33	1.33	1.34	1.36	1.37	1.39
Total	**34.63**	**34.87**	**35.47**	**34.35**	**34.84**	**34.79**	**32.75**	**32.17**	**29.99**	**31.65**

Note: Totals may not sum due to independent rounding.

Methane is produced during anaerobic decomposition of organic matter in biological systems. Decomposition occurring in landfills accounts for the majority of anthropogenic methane emissions in California and in the United States as a whole. The decline in landfill methane emissions between 1990 and 1999 is primarily due to an increase in the prevalence of landfill gas controls. Agricultural processes such as enteric fermentation, manure management, and rice cultivation are also significant sources of methane in California.

Smaller quantities of methane are emitted during the production and distribution of natural gas and petroleum and as a by-product of coal mining and incomplete fossil fuel combustion. (See Figure 1-6.)

Figure 1-6: 1999 CH$_4$ Emissions in California by Sector
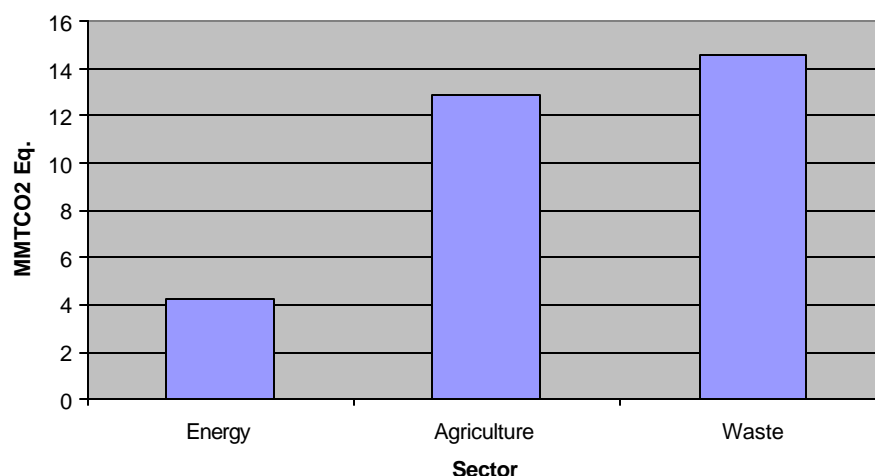
Energy

Energy-related methane emissions in California accounted for 4.2 MMTCO$_2$ Eq. in 1999, nearly 69 percent of which were attributable to natural gas systems in the state (see Figure 1-7). Emissions from coal mining, responsible for nearly 10 percent of U.S. CH$_4$ emissions in 1999, were zero in 1999 and negligible for the entire ten-year period. Methane emissions from petroleum systems, stationary source combustion, and mobile source combustion decreased slightly between 1990 and 1999, in line with national trends.

Agriculture

Methane emissions from agriculture were driven by enteric fermentation and manure management, which represented 55 and 41 percent of 1999 agricultural CH$_4$ emissions, respectively. (See Figure 1-8.)

Methane produced through the process of enteric fermentation accounted for emissions of 7.5 MMTCO$_2$ Eq. in 1990 and 7.1 MMTCO$_2$ Eq. in 1999. Overall, emissions from this source decreased by 6 percent between 1990 and 1999. The main driver for this decrease was the declining beef cattle population in California.

Methane emissions from manure management in 1999 were 5.2 MMTCO$_2$ Eq. Dairy cattle accounted for the majority of CH$_4$ emissions from manure management, followed by poultry, beef cattle, swine, horses, sheep and goats.

Rice cultivation and agricultural residue burning were smaller sources of CH$_4$ emissions in California. In 1999, CH$_4$ emissions from these sources totaled approximately 0.56 MMTCO$_2$ Eq., roughly 4 percent, of agricultural CH$_4$ emissions.

Figure 1-7: 1999 CH$_4$ Emissions from Energy by Source

Stationary Source Combustion 13%

Petroleum Systems 8%

Mobile Source Combustion 10%

Natural Gas Systems 69%
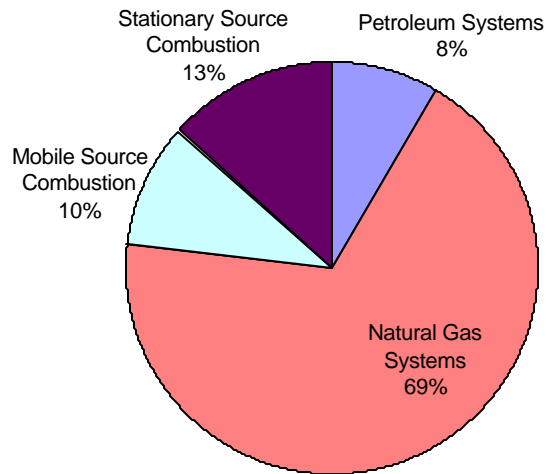
Figure 1-8: 1999 CH$_4$ Emissions from Agriculture by Source

Manure Management 41%

Flooded Rice Fields 4%

Burning Agricultural Residues

Enteric Fermentation 55%
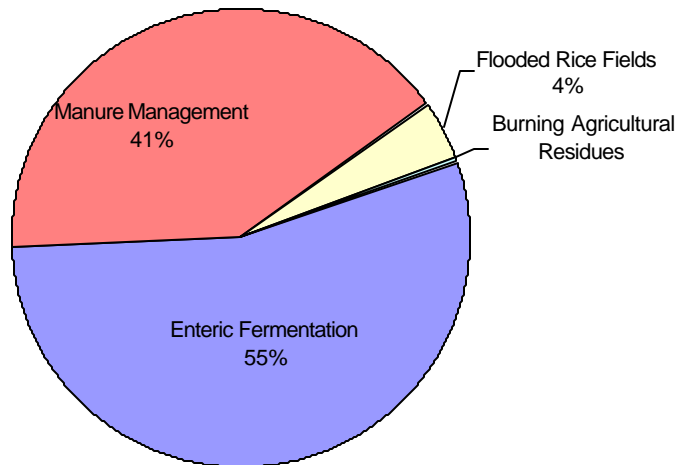
Waste

The waste sector was responsible for the majority of CH$_4$ emissions in California, with landfills accounting for 42 percent and wastewater accounting for roughly 4 percent of 1999 CH$_4$ emissions. As mentioned above, anaerobic decomposition in landfills is also the greatest source of anthropogenic CH$_4$ emissions in the United States, accounting for 35 percent of national CH$_4$ emissions.

Landfills dominated waste sector CH$_4$ emissions, representing more than 90 percent of emissions. Two key factors influencing landfill CH$_4$ emissions include the quantity of solid waste in landfills (waste-in-place) that is less than thirty years old and the quantity of CH$_4$ recovered for energy projects or flared. The total amount of waste-in-place in California landfills increased from 760 million tons in 1990 to 932 million tons in 1999, a gain of 23 percent. This increase resulted in an increase in CH$_4$

generation from 27.1 MMTCO$_2$ Eq. in 1990 to 31.8 MMTCO$_2$ Eq. in 1999. The amount of CH$_4$ recovered, meanwhile, increased from 7.6 MMTCO$_2$ Eq. to 15.7 MMTCO$_2$ Eq. during this period.

The net effect of these two trends – the relatively modest increase in CH$_4$ generation coupled with the large increase in recovery – was a 22 percent decrease in net landfill emissions over the ten-year period.
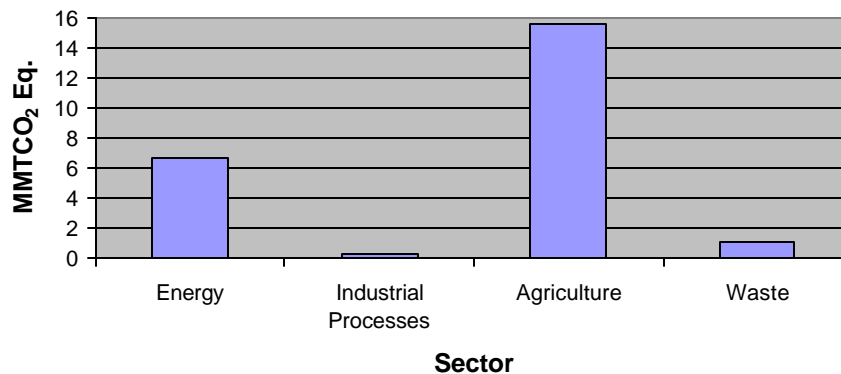
Nitrous Oxide Emissions

Nitrous oxide emissions accounted for nearly 6 percent of gross 1999 emissions in California. The primary sources of anthropogenic nitrous oxide emissions in California are agricultural soil management and fossil fuel combustion in mobile sources (See Table 1-6 and Figure 1-9. Other, smaller sources include stationary source combustion, nitric acid production, manure management, agricultural residue burning, waste combustion, and human sewage.

Table 1-6: N$_2$O Emissions by Sector: 1990-1999 (MMTCO$_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Energy	**7.28**	**7.49**	**7.59**	**7.55**	**7.44**	**7.20**	**7.02**	**6.75**	**6.67**	**6.63**
Mobile Source Combustion	6.82	7.06	7.15	7.14	7.02	6.81	6.63	6.39	6.32	6.24
Stationary Source Combustion	0.46	0.43	0.44	0.41	0.42	0.40	0.39	0.36	0.35	0.39
Industrial Processes	**0.53**	**0.52**	**0.56**	**0.38**	**0.38**	**0.49**	**0.30**	**0.30**	**0.28**	**0.28**
Nitric Acid Production	0.53	0.52	0.56	0.38	0.38	0.49	0.30	0.30	0.28	0.28
Agriculture	**15.82**	**14.19**	**14.50**	**15.51**	**14.86**	**16.76**	**16.32**	**14.92**	**15.26**	**15.57**
Agricultural Soils	14.93	13.35	13.68	14.69	14.04	15.93	15.51	14.10	14.45	14.74
Manure Management	0.81	0.76	0.74	0.72	0.70	0.72	0.70	0.70	0.70	0.71
Burning Agricultural Residues	0.09	0.08	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.12
Waste	**0.96**	**0.89**	**0.88**	**0.96**	**0.89**	**0.96**	**0.93**	**1.03**	**1.06**	**1.08**
Waste Combustion	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Human Sewage	0.93	0.87	0.85	0.94	0.86	0.93	0.91	1.00	1.04	1.05
Total	**24.60**	**23.09**	**23.52**	**24.41**	**23.56**	**25.40**	**24.57**	**23.00**	**23.28**	**23.55**

Note: Totals may not add due to rounding.

Figure 1-9: 1999 N$_2$O Emissions in California by Sector

Energy

Nitrous oxide emissions from mobile source combustion were responsible for the majority (94 percent) of energy sector N$_2$O emissions, with emissions from stationary source combustion representing the remainder.

In 1999, N$_2$O emissions from mobile source combustion were 6.24 MMTCO$_2$ Eq., representing more than 26 percent of state N$_2$O emissions. From 1990 to 1999, emissions of N$_2$O decreased by 9 percent. Decreased emissions were attributable to reductions in emissions from gasoline passenger cars and gasoline light-duty trucks, which constitute the majority of emissions in California.

Industrial Processes

Nitric acid production was the only industrial source of N$_2$O emissions in California, accounting for roughly 1 percent of state N$_2$O emissions.

Agriculture

Agriculture Soil management dominated agricultural emissions of N$_2$O, representing 95 percent of emissions from this sector. Emissions from agricultural soils accounted for 14.7 MMTCO$_2$ Eq. in 1999, representing roughly 63 percent of state N$_2$O emissions. Direct emissions from agricultural soils decreased by 3.5 percent, while indirect emissions remained relatively constant through the ten-year period. Nitrous oxide emissions from the sector as a whole decreased by just over one percent from 1990 through 1999, mainly as a result of a slight decline in fertilizer consumption.

Smaller sources of N$_2$O emissions from agriculture included manure management and agricultural residue burning, which accounted for 3 percent and 0.5 percent of state N$_2$O emissions in 1999, respectively.

Waste

Sources of N$_2$O emissions from the waste sector included human sewage and waste combustion. Human sewage was the third largest source of N$_2$O emissions in the state, accounting for more than 1 MMTCO$_2$ Eq. in 1999. Emissions from waste combustion were relatively minor, accounting for 0.02 MMTCO2 Eq. in 1999.

HFC, PFC, and SF_6 Emissions

HFCs, PFCs, and SF_6 are powerful greenhouse gases. HFCs are primarily used as substitutes for ozone-depleting substances (ODS) regulated under the Montreal Protocol. PFCs and SF_6 are generally emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. There is no aluminum production or magnesium production in California; therefore these sources of high GWP gases are excluded from this report.

All high GWP gas emissions are estimated in the Industrial Process chapter of the inventory. (See Table 1-7.)

Table 1-7: High GWP Gas Emissions by Sector: 1990-1999 (MMTCO$_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Industrial Processes	**2.07**	**2.09**	**2.29**	**2.84**	**3.54**	**5.43**	**6.81**	**7.87**	**8.73**	**9.70**
Substitution of Ozone Depleting Substances	0.12	0.10	0.19	0.65	1.23	2.94	4.15	5.15	6.10	7.00
Semiconductor Manufacture	0.36	0.36	0.36	0.46	0.52	0.67	0.86	0.86	0.84	0.84
Electric Utilities	1.60	1.63	1.74	1.74	1.80	1.81	1.81	1.87	1.80	1.87
Total	**2.07**	**2.09**	**2.29**	**2.84**	**3.54**	**5.43**	**6.81**	**7.87**	**8.73**	**9.70**

Note: Totals may not add due to rounding.

Industrial Processes

Emissions from ODS substitutes were responsible for 72 percent of emissions of HFCs, PFCs, and SF_6. (See Figure 1-10.)

The use and subsequent emissions of HFCs and PFCs as ODS substitutes has been increasing from small amounts in 1990 to 7.00 MMTCO$_2$ Eq. in 1999. Although the absolute magnitude of emissions from ODS substitutes is relatively small (2 percent of gross California emissions in 1999), its growth has been faster than any other sector. The increase has been driven by efforts to phase out ODS in the United States and the trends of ODS substitute emissions in California echo the trends that have been seen on a national level. In the early 1990s, ODS substitute emissions primarily consisted of HFC-134a from refrigeration and motor vehicle air conditioning end-uses. By the mid-1990s, other end-uses, such as foam blowing, aerosol propellants, solvents and sterilization, began using a larger variety of high-GWP substitutes. By 1995, ODS substitutes for halons entered widespread use in the United States as halon production was phased-out.

Semiconductor manufacture and electric utilities were responsible for 28 percent of high GWP gas emissions in 1999. Emissions from semiconductor manufacturing grew from 0.36 MMTCO$_2$ Eq. in 1990 to 0.84 MMTCO$_2$ Eq. in 1999, representing an increase of over 130 percent. This rapid growth is the result of not only the rapid growth in the semiconductor industry, but also the increasing complexity of semiconductor products, which leads to greater use of PFCs per semiconductor chip. Emissions from electric utilities increased more modestly (by approximately 17 percent), reflecting an increase in electricity consumption in the state.

Figure 1-10: 1999 High GWP Gas Emissions by Industrial Processes Sub-Sector

Electric Utilities 19%

Semiconductor Manufacture 9%

Substitution of Ozone Depleting Substances 72%
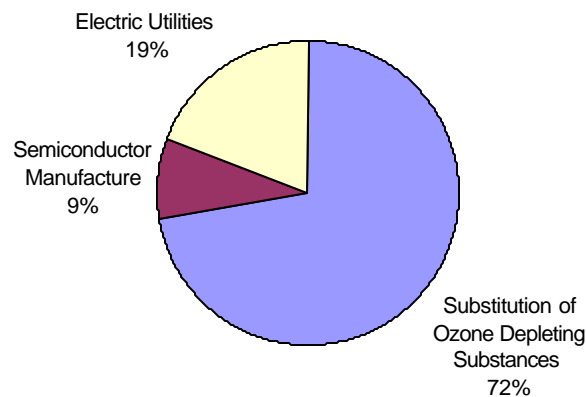
The remainder of this report is organized as follows:

- Chapter 2: Energy
- Chapter 3: Industrial Processes
- Chapter 4: Agriculture
- Chapter 5: Land-Use Change and Forestry
- Chapter 6: Waste
- Chapter 7: California Emissions in Context

Chapter 2

Energy

The majority of California's anthropogenic greenhouse gas emissions come from energy-related activities. This chapter addresses carbon dioxide (CO_2) emissions from fossil fuel combustion; methane (CH_4) and nitrous oxide (N_2O) emissions from stationary source combustion and mobile source combustion; CH_4 emissions from coal mining, natural gas systems, petroleum systems; and CO_2, CH_4, and N_2O emissions from and international bunker fuels.

Table 2-1 presents a summary of energy-related emissions in California. Fossil fuel combustion is the largest source of greenhouse gas emissions in the state, comprising 99 percent of California's energy-related emissions and 83 percent of gross emissions in 1999. Overall, energy emissions in California totaled 367 million metric tons of carbon dioxide equivalent (MMTCO$_2$ Eq.) in 1999. These emissions account for approximately 6 percent of U.S. energy emissions.

Table 2-1: Emissions from Energy (MMTCO$_2$ Eq.)

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO$_2$	**358.16**	**345.27**	**337.80**	**333.51**	**350.00**	**340.39**	**340.87**	**342.09**	**349.33**	**356.28**
Fossil Fuel Combustion	358.16	345.27	337.80	333.51	350.00	340.39	340.87	342.09	349.33	356.28
Int. Bunker Fuels	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH$_4$	**5.15**	**5.06**	**5.16**	**4.60**	**4.47**	**4.54**	**4.44**	**4.24**	**4.18**	**4.23**
Natural Gas Systems	3.34	3.24	3.19	3.05	2.94	3.00	2.91	2.91	2.87	2.90
Coal Mining	0.18	0.19	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum Systems	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.38	0.38	0.36
Stationary Sources	0.69	0.71	0.73	0.67	0.67	0.69	0.69	0.52	0.52	0.56
Mobile Sources	0.54	0.52	0.51	0.49	0.48	0.46	0.44	0.43	0.42	0.41
Int. Bunker Fuels	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
N$_2$O	**7.28**	**7.49**	**7.59**	**7.55**	**7.44**	**7.20**	**7.02**	**6.75**	**6.67**	**6.63**
Stationary Sources	0.46	0.43	0.44	0.41	0.42	0.40	0.39	0.36	0.35	0.39
Mobile Sources	6.82	7.06	7.15	7.14	7.02	6.81	6.63	6.39	6.32	6.24
Int. Bunker Fuels	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total	**370.60**	**357.83**	**350.55**	**345.67**	**361.91**	**352.14**	**352.32**	**353.08**	**360.18**	**367.14**

Note: Totals may not sum due to independent rounding.

CO$_2$ from Fossil Fuel Combustion

Emissions from the combustion of fossil fuels account for the majority of greenhouse gases emitted in California, as in the United States as a whole. When these fuels are burned to produce energy, the majority of the carbon they contain is released to the atmosphere as CO$_2$. This section quantifies these emissions for California. Smaller quantities of methane and N$_2$O are also released during combustion; emissions of these gases are estimated later in this chapter under Stationary Source Combustion and Mobile Source Combustion.

Fossil fuels combusted for energy include coal, petroleum, and natural gas. In order to analyze patterns of energy use and related CO$_2$ emissions, the discussion of fossil fuel combustion is divided into five sectors: residential, commercial, industrial, transportation, and electric power. Note that for this emissions analysis, total energy consumption was adjusted to remove consumption of fuels for non-energy purposes. Non-energy uses primarily consist of the manufacturing of certain fossil fuels into products, which allows for storage of carbon for long periods of time. Bunker fuels, which are fuels used for international transport, are generally excluded from totals in accordance with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997). However, emissions attributable to bunker fuels were not excluded from the reported totals for this inventory. The estimates that include contributions from bunker fuels are CO$_2$ from fossil fuel combustion and methane and N$_2$O from mobile sources.

Total CO$_2$ emissions from fossil fuel combustion in California in 1999 were 356.3 MMTCO$_2$ Eq., which accounts for approximately 6 percent of the U.S. emissions from this source. As seen in Table 2-2, total emissions from fossil fuel combustion were at their highest in 1990, underwent a rise and fall in 1994 and 1995, respectively, and then rose again from 1996 through 1999. Carbon dioxide emissions from petroleum accounted for the majority (about 67 percent) of total CO$_2$ emissions from fossil fuel combustion in California (see Figure 2-1). Consumption of petroleum occurred mostly in the industrial and transportation sectors, while over half of the natural gas consumed was in the industrial sector. Note in Table 2-2 that natural gas consumption in the industrial sector increased approximately 97 percent from 1990. Emissions from coal in the electric power and in other sectors were minor, especially compared to the rest of the U.S..

The transportation sector accounted for the largest portion of emissions, averaging 59 percent of the total CO$_2$ emissions from fossil fuel combustion in California between 1990 and 1999. Transportation fossil fuel combustion did not fluctuate significantly during the 1990s, remaining around 200 MMTCO$_2$ Eq. Petroleum products accounted for nearly all of the consumption in this sector.

Energy use in the industrial sector ranked second to transportation in terms of total CO$_2$ emissions from fossil fuel combustion in California (about 22 percent on average in the 1990s). From 1990 to 1999, industrial emissions of CO$_2$ increased 28 percent. Decreases in petroleum consumption were overshadowed by steep growth in natural gas consumption in this sector. Fuel consumption in this sector occurs from manufacturing, construction, mining, and agricultural activities. Currently, this sector includes consumption from non-utility electricity generation, which creates an overestimation of emissions from this sector, as both utility and non-utility electricity generation should be included within the electric power sector.

In 1999, the residential and commercial sectors accounted for 9 and 4 percent of total emissions from fossil fuel combustion in California, respectively. Energy use in the residential sector stayed relatively constant around 29 MMTCO$_2$ Eq. during the 1990s, while commercial energy use decreased 25 percent over the same period. However, in 1998 both sectors witnessed a noticeable rise in fuel consumption and consequent emissions (see Table 2-2). Natural gas and petroleum were consumed in these sectors for heating and cooking; coal use was negligible.

On average, electric power generation accounted for roughly 7 percent of total CO$_2$ emissions. Carbon dioxide emissions from the electric power sector dropped 73 percent from 28.5 MMTCO$_2$ Eq. in 1990 to 7.7 MMTCO$_2$ Eq. by 1999. Natural gas accounted for almost all (99 percent) sectoral emissions in 1999. As mentioned above, consumption from non-utility electricity generation is currently included in the industrial sector, leading to an underestimation of emissions from the electric power sector.

Table 2-2: Emissions of CO$_2$ from Fossil Fuel Combustion (MMTCO$_2$ Eq.)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Residential	**29.5**	**29.3**	**27.2**	**28.8**	**29.4**	**26.8**	**27.0**	**26.8**	**32.1**	**32.0**
Coal	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Petroleum	1.4	1.7	1.2	1.2	1.2	1.2	1.0	0.9	1.5	1.4
Natural Gas	28.0	27.6	26.0	27.5	28.1	25.5	25.8	25.7	30.5	30.6
Commercial	**18.9**	**18.8**	**17.1**	**14.9**	**15.3**	**16.4**	**14.1**	**14.9**	**17.3**	**14.2**
Coal	0.0	0.1	0.0	0.2	0.2	0.2	0.3	0.2	0.2	0.0
Petroleum	3.4	3.2	1.6	1.0	0.9	1.3	1.0	1.1	1.4	1.0
Natural Gas	15.5	15.6	15.5	13.7	14.1	14.9	12.8	13.6	15.7	13.2
Industrial	**72.5**	**74.8**	**73.1**	**72.7**	**71.3**	**71.2**	**74.7**	**76.7**	**81.7**	**92.5**
Coal	6.0	5.8	5.9	4.9	5.0	5.3	4.6	4.3	5.7	5.8
Petroleum	35.6	31.9	30.9	28.0	28.5	26.8	29.8	30.1	27.6	25.6
Natural Gas	31.0	37.1	36.3	39.8	37.8	39.1	40.3	42.2	48.4	61.1
Transportation	**208.8**	**197.5**	**189.4**	**190.2**	**199.9**	**204.2**	**207.4**	**203.4**	**203.6**	**209.9**
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum	207.7	196.5	188.6	189.5	199.2	203.2	206.3	202.0	203.0	209.2
Natural Gas	1.1	1.0	0.8	0.7	0.7	1.1	1.1	1.3	0.6	0.7
Electric Power	**28.5**	**24.9**	**31.1**	**27.0**	**34.1**	**21.8**	**17.8**	**20.5**	**14.7**	**7.7**
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum	3.6	0.5	0.3	1.6	1.4	0.4	0.5	0.1	0.1	0.1
Natural Gas	24.9	24.4	30.8	25.3	32.7	21.4	17.2	20.3	14.6	7.7
Total	**358.2**	**345.3**	**337.8**	**333.5**	**350.0**	**340.4**	**340.9**	**342.1**	**349.3**	**356.3**
Coal	6.0	5.9	5.9	5.2	5.3	5.6	4.9	4.5	5.9	5.9
Petroleum	251.7	233.8	222.5	221.3	231.3	232.8	238.7	234.3	233.6	237.3
Natural Gas	100.5	105.6	109.3	107.0	113.4	102.0	97.2	103.3	109.8	113.1

Note: Totals may not sum due to independent rounding.

Figure 1: Fuel Type Contribution to CO$_2$ Emissions from Fossil Fuel Combustion
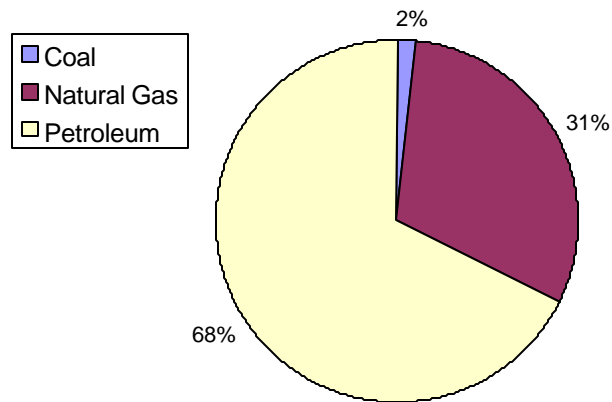
Methodology

The methodology for estimating CO$_2$ emissions from fossil fuel combustion is data-intensive, but produces emission estimates that are thought to be among the most accurate in the entire inventory. The methods used for this analysis are taken from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001) and the *Emission Inventory Improvement Program (EIIP)* guidance (EIIP 1999). These methods were developed to conform to internationally approved methods provided in the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997).

The following steps characterize the methodology used to estimate CO$_2$ from fossil fuel combustion in California:

Step 1: Obtain Data on Fuel Consumption by Fuel Type and Sector.

California energy consumption data from each sector (i.e., residential, commercial, industrial, transportation, and electric power) were collected by primary fuel type (e.g., coal, petroleum, gas) and secondary fuel type (e.g., motor gasoline, distillate fuel oil). Table 2-3 shows all sectors and fuel types included, and Table 2-4 presents combustion by sector and fuel type.

Step 2: Determine the Total Carbon Content of Fuels Consumed.

Carbon content coefficients, which reflect the amount of carbon in each fuel type, were multiplied by energy consumption to yield potential carbon emissions. This estimate defines the maximum amount of carbon that could potentially be released to the atmosphere if all of the carbon in each fuel were converted to CO$_2$. Table 2-5 provides a list of carbon contents used in this analysis. The carbon content of some fuel types varies annually, due to fluctuations in fuel quality specific to California; carbon contents for these fuel types are provided in Table 2-6.

Step 3: Subtract the Total Carbon Stored in Products.

Some or all of the carbon from certain fuels can be stored for a long period of time through non-energy uses. These end-uses sequester varying amounts of carbon. For example, asphalt, an end product of petroleum, can sequester almost 100 percent of its

carbon over a significant period of time, while lubricants lose or emit some carbon when they are used. To correct for this, a fuel-specific storage factor was multiplied by the amount consumed for non-energy purposes and the product (stored carbon) was subtracted from potential carbon emission estimates. Fuel-specific storage factors are provided in Table 2-5.

Step 4: Subtract the Carbon Content of Bunker Fuels Consumed.

Emissions from international transportation activities, or bunker fuels, should be excluded from the total California emission estimates in accordance with the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997). Although California has both aviation and marine fuels that fall under this category, only marine fuels were estimated due to data limitations. The total carbon in distillate and residual marine fuels consumed were subtracted from the total potential carbon emissions. To calculate carbon content of bunker fuels, a similar methodology was used, as described in the section entitled "International Bunker Fuels."

The quality and availability of data on international bunker fuel consumption was not adequate to develop complete estimates of emissions from this source. Therefore, California's emissions from fossil fuel combustion are not adjusted to reflect emissions from bunker fuels. For more information on bunker fuels, consult the section of this chapter on International Bunker Fuels.

Step 5: Adjust for Carbon that Does Not Oxidize During Combustion.

A small amount of the carbon in fuels is not emitted to the atmosphere because of inefficiencies in the combustion processes, remaining behind as soot. To account for this unoxidized carbon, the net carbon content for each fuel was multiplied by 1 percent for petroleum and coal and 0.5 percent for natural gas, which are assumed to represent the amount of unoxidized carbon during combustion (see Table 2-5).

Step 6: Convert Carbon Emissions to CO$_2$ Emissions.

Carbon emissions from energy consumption were then converted to metric tons by multiplying by 0.0004536 metric tons per pound. This product is then multiplied by the molecular weight ratio of CO$_2$ to carbon to obtain metric tons of CO$_2$ equivalent.

The methodology above can be summarized by the following equation:

$$CO_2 \text{ emissions} = \Sigma \left[(FC_i \times CC_i) - SC_i - BF_i \right] \times FO_i \times \frac{0.0004536 \text{ MTC}}{\text{lb C}} \times \frac{44 \text{ CO}_2}{12 \text{ C}}$$

Where:
Σ indicates the sum across all fuel types
FC_i = fuel combusted for fuel i (million Btu)
CC_i = carbon content coefficient for fuel i (lbs C/million Btu)
SC_i = stored carbon for fuel i (lbs C)
BF_i = carbon in bunker fuels for fuel i (lbs C)
FO_i = fraction oxidized for fuel i (percent)

Table 2-3: Fuel Types by Sector for Estimating CO_2 Emissions from Fossil Fuel Combustion

Residential	Commercial	Industrial	Transportation	Electric Power
Coal	Coal	Coking Coal Other Coal	Coal	Coal
Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Petroleum: Distillate Fuel Kerosene LPG	Petroleum: Distillate Fuel Kerosene LPG Motor Gasoline Residual Fuel	Petroleum: Distillate Fuel Kerosene LPG Motor Gasoline Residual Fuel Lubricants Asphalt & Road Oil Crude Oil Feedstocks Misc. Petroleum Products Petroleum Coke Pentanes Plus Still Gas Special Napthas Unfinished Oils Waxes Aviation Gasoline Blending Components Motor Gasoline Blending Components	Petroleum: Distillate Fuel LPG Motor Gasoline Residual Fuel Lubricants Aviation Gasoline Jet Fuel, Kerosene Jet Fuel, Naphtha	Petroleum: Distillate Fuel Residual Fuel Petroleum Coke

Source: EIA 1999, EPA 2001

Data Sources

The following data were obtained for the estimation of CO_2 emissions from fossil fuel combustion:

- fossil fuel energy consumption by sector and energy type;
- carbon content coefficients;
- fraction of carbon oxidized;
- marine bunker fuel consumption; and
- carbon storage factors.

California energy consumption data from 1990 to 1999 was obtained almost entirely from the *State Energy Data Report (SEDR), 1999* published by the U.S. Department of Energy's Energy Information Administration (EIA 1999). Industrial still gas data was taken from the *Petroleum Industry Information Reporting Act*, which receives this information directly from the California refineries – allowing for a more accurate reflection of the actual data (PIIRA 2001). The consumption activity data by sector and fuel type used to estimate emissions of CO_2 from fossil fuel combustion are provided in Table 2-4.

Motor gasoline consumption data was obtained from the California Board of Equalization (BOE 2001). This information was based on collection of taxes on the sale of gasoline. Aviation gasoline included in the BOE data was subtracted out using aviation gasoline consumption data provided by the SEDR (EIA 1999). Consumption data reported by BOE for fiscal years was adjusted to calendar year data. To convert

from fiscal years to calendar years, it was assumed that motor gasoline consumption is equally distributed throughout the entire year. For a fiscal year, half the consumption occurs between January 1 and June 30, and half between July 1 and December 31. Using this assumption, two consecutive fiscal years were averaged together to obtain data for the calendar year in common to both fiscal years.

Carbon content coefficients were taken primarily from chapter 1 of the EIIP guidance (EIIP 1999) (see Table 2-5). The carbon content coefficient for crude oil was taken from the U.S. Inventory (EPA 2001). These values are consistent with EIA's national carbon factors. The fraction of carbon oxidized during combustion for each fuel is also consistent with the values used in the national inventory and in IPCC guidance (EPA 2001, IPCC/UNEP/OECD/IEA 1997) (see Table 2-5). The variable carbon contents were taken from the *SEDR* (EIA 1999) (see Table 2-6). Data sources used to estimate international bunker fuel emissions are discussed in the section "International Bunker Fuels." Non-energy use fuel carbon storage factors were obtained from both IPCC and the U.S. Inventory (IPCC/UNEP/OECD/IEA 1997, EPA 2001) (see Table 2-5).

Table 2-4: Energy Consumption for California (TBtu)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Residential	**554**	**549**	**511**	**541**	**552**	**504**	**506**	**503**	**603**	**601**
Coal	0	0	0	1	1	1	1	1	1	0
Natural Gas	531	522	493	520	532	484	489	487	578	579
Petroleum	23	27	19	19	19	19	16	15	24	22
Commercial	**341**	**340**	**316**	**276**	**283**	**303**	**260**	**275**	**319**	**264**
Coal	0	1	0	2	3	2	3	2	2	0
Natural Gas	294	295	293	260	267	282	243	258	297	249
Petroleum	47	44	23	14	13	18	14	15	20	15
Industrial	**1,284**	**1,330**	**1,305**	**1,318**	**1,295**	**1,286**	**1,331**	**1,366**	**1,480**	**1,740**
Coal	65	63	65	54	54	58	50	47	62	63
Natural Gas	607	726	706	775	741	764	787	826	947	1,196
Petroleum	677	604	599	543	553	522	544	540	534	544
Transportation	**2,896**	**2,747**	**2,638**	**2,648**	**2,780**	**2,839**	**2,887**	**2,841**	**2,843**	**2,926**
Coal	0	0	0	0	0	0	0	0	0	0
Natural Gas	21	19	15	13	13	20	20	25	12	13
Petroleum	2,875	2,728	2,623	2,636	2,767	2,819	2,867	2,816	2,831	2,913
Electric Power	**518**	**468**	**587**	**501**	**637**	**411**	**333**	**387**	**278**	**146**
Coal	0	0	0	0	0	0	0	0	0	0
Natural Gas	471	462	583	480	619	405	326	385	276	146
Petroleum	46	6	4	21	19	5	7	2	2	1
Total	**5,592**	**5,434**	**5,356**	**5,284**	**5,548**	**5,342**	**5,318**	**5,373**	**5,523**	**5,677**
Coal	65	64	65	57	58	61	54	49	64	64
Natural Gas	1,924	2,024	2,089	2,048	2,172	1,956	1,865	1,982	2,110	2,182
Petroleum	3,668	3,409	3,267	3,233	3,372	3,383	3,449	3,388	3,411	3,494

Source: EIA 1999, BOE 2001, PIIRA 2001
Note: Totals may not sum due to independent rounding.

Table 2-5: Carbon Content Coefficients, Storage Factors, and Fraction Oxidized

Fuel Type	Carbon Content Coefficient (lbs C/MMBtu)[b]	Storage Factor (for Non-Energy Uses)	Fraction Oxidized
Coal			
Residential Coal	[a]		99.0%
Commercial Coal	[a]		99.0%
Industrial Coking Coal	[a]	75%	99.0%
Industrial Other Coal	[a]		99.0%
Utility Coal	[a]		99.0%
Natural Gas	31.9	91%	99.5%
Petroleum			99.0%
Asphalt and Road Oil	45.5	100%	99.0%
Aviation Gasoline	41.6		99.0%
Distillate Fuel	44.0	50%	99.0%
Jet Fuel, Kerosene	43.5		99.0%
Jet Fuel, Naphtha	44.0		99.0%
Kerosene	43.5		99.0%
Liquefied Petroleum Gas (LPG)	37.8	91%	99.0%
Lubricants	44.6	9%	99.0%
Motor Gasoline	42.8		99.0%
Residual Fuel	47.4	50%	99.0%
Misc. Petroleum Products	44.7	100%	99.0%
Naphtha	40.0	91%	99.0%
Other Oil	44.0	91%	99.0%
Pentanes Plus	40.2	91%	99.0%
Petroleum Coke	61.4	50%	99.0%
Still Gas	38.6	80%	99.0%
Special Naphtha	43.8	0%	99.0%
Unfinished Oils	44.6		99.0%
Waxes	43.7	100%	99.0%
Crude Oil[c]	44.6		99.0%
Aviation Gasoline Blending Components[d]	41.6		99.0%
Motor Gasoline Blending Components[d]	42.8		99.0%

Source: All carbon content values from EIIP 1999, except crude oil, aviation gasoline blending components, and motor gasoline blending components, which are taken from EPA 2001, and jet fuel, kerosene and jet fuel, naphtha which are taken from EIA 1994. Storage factors are taken from IPCC/UNEP/OECD/IEA 1997 and EPA 2001. Estimates of the fraction of carbon oxidized for various fuel types were taken from EPA 2001.

[a] These coefficients vary annually due to fluctuations in fuel quality (see Table 5).
[b] Carbon contents are higher heating value.
[c] Used the average of the 1990-1999 carbon content for crude oil in Tg C/QBtu and converted to lbs C/million Btu.
[d] Carbon loads of blending components equal those of the gasolines they add to.

Table 2-6: Annually Variable Carbon Contents for California

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Residential Coal	55.66	55.69	55.66	55.66	55.66	55.66	55.66	55.66	55.67	55.66
Commercial Coal	55.66	55.69	55.66	55.66	55.66	55.66	55.66	55.66	55.67	55.66
Industrial Coking Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Other Coal	55.80	55.80	55.69	55.66	55.66	55.66	55.66	55.71	55.79	55.80
Utility Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: EIA 1999

CH$_4$ and N$_2$O from Stationary Source Combustion

Stationary source combustion includes all fuel combustion activities except for transportation (i.e. mobile source combustion). Methane and N$_2$O emissions from the residential, industrial, commercial/institutional, and utilities sectors are described here, as CO$_2$ emissions from stationary sources are covered earlier in this chapter. Non-CO$_2$ emissions originate from the combustion of coal, petroleum, natural gas, and wood, and are dependent on a variety of factors including: fuel characteristics, type and age of the technology, environmental surroundings, and the use of pollution control devices.

Stationary source combustion in 1999 resulted in the emission of 0.56 MMTCO$_2$ Eq. of CH$_4$ and 0.39 MMTCO$_2$ Eq. of N$_2$O, for a total of 0.95 MMTCO$_2$ Eq. of non-CO$_2$ emissions. California contributed approximately 7 percent of the nation's CH$_4$ emissions and 2 percent (see Tables 2-7 and 2-8) of the N$_2$O emissions from this source category.

Methane emissions remained approximately constant from 1990 to 1996 and then dropped 19 percent from 1996 to 1999. The recent decrease in CH$_4$ emissions is principally due to a decline in wood consumption in the residential sector. Emissions of N$_2$O exhibited a more constant decreasing trend from 1990 to 1999, dropping by about 15 percent over the period.

Table 2-7: CH$_4$ Emissions from Stationary Source Combustion (MMTCO$_2$ Eq.)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Electric Power	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.00**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	**0.17**	**0.17**	**0.18**	**0.19**	**0.23**
Coal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Petroleum	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Natural Gas	0.06	0.07	0.07	0.08	0.07	0.08	0.08	0.08	0.09	0.12
Wood	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.06	0.07
Commercial/Institutional	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.05**	**0.06**	**0.06**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.02
Wood	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03
Residential	**0.44**	**0.46**	**0.47**	**0.42**	**0.42**	**0.45**	**0.45**	**0.28**	**0.27**	**0.28**
Coal	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Petroleum	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Natural Gas	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06
Wood	0.38	0.40	0.42	0.36	0.35	0.39	0.39	0.23	0.20	0.21
Total	**0.69**	**0.71**	**0.73**	**0.67**	**0.67**	**0.69**	**0.69**	**0.52**	**0.52**	**0.56**

Note: Totals may not sum due to independent rounding.

Table 2-8: N$_2$O Emissions from Stationary Source Combustion, 1990-1999 (MMTCO$_2$ Eq.)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Electric Utilities	**0.02**	**0.01**	**0.02**	**0.02**	**0.02**	**0.01**	**0.01**	**0.01**	**0.01**	**0.00**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.00
Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	**0.32**	**0.30**	**0.30**	**0.28**	**0.29**	**0.27**	**0.27**	**0.27**	**0.26**	**0.31**
Coal	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.03
Petroleum	0.12	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Natural Gas	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04
Wood	0.15	0.14	0.14	0.14	0.14	0.13	0.12	0.13	0.11	0.14
Commercial/Institutional	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Wood	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01
Residential	**0.09**	**0.10**	**0.10**	**0.09**	**0.09**	**0.09**	**0.09**	**0.06**	**0.06**	**0.06**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02
Wood	0.07	0.08	0.08	0.07	0.07	0.08	0.08	0.04	0.04	0.04
Total	**0.46**	**0.43**	**0.44**	**0.41**	**0.42**	**0.40**	**0.39**	**0.36**	**0.35**	**0.39**

Note: Totals may not sum due to independent rounding.

Methodology

Methane and N$_2$O emissions from stationary combustion in California were estimated following the Tier 1 method in the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997), the same approach used in the U.S. Inventory (EPA 2001).

Emissions of CH$_4$ and N$_2$O were estimated from four primary fuel types—coal, oil, natural gas, and wood. The consumption data for each fuel type were grouped into four sectors (e.g. industrial, residential, commercial/institutional, and electric utilities) and then multiplied by IPCC emission factors specific to each fuel type and sector (IPCC/UNEP/OECD/IEA 1997).

Annual energy consumption data for each primary fuel type were obtained for each sector (see Table 2-9). These data were then converted from gross calorific values (GCV) (i.e., higher heating values) to net calorific values (NCV) (i.e., lower heating values), as the IPCC emission factors are based on NCV. To make this adjustment, a 10 percent reduction for natural gas and wood, and a 5 percent reduction for coal and oil were assumed; thus natural gas and wood values were multiplied by 0.90 while coal and oil values were multiplied by 0.95.

The consumption data were then converted into gigajoules (GJ) and multiplied by the appropriate emission factor (in g/GJ) to estimate emissions of each gas. These values were then multiplied by the global warming potential (GWP) for each gas, 21 for CH$_4$ and 310 for N$_2$O, to express emissions in CO$_2$ equivalents.

Data Sources

Energy consumption data by sector and primary fuel type were obtained primarily from the *State Energy Data Report (SEDR), 1999* (EIA 1999). Industrial still gas data was taken from the *Petroleum Industry Information Reporting Act*, which receives this information directly from California refineries, and is thus a more accurate accounting than the EIA SEDRs (PIIRA 2001). The assumption used to convert from GCV to NCV was a basic version of the International Energy Agency's convention and is consistent with the U.S. Inventory (EPA 2001). All emission factors were taken from the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997) (see Table 2-10).

Table 2-9: Energy Consumption Data by Sector and Fuel Type (TBtu)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Electric Utilities	**518**	**468**	**587**	**501**	**637**	**411**	**333**	**387**	**278**	**146**
Coal	0	0	0	0	0	0	0	0	0	0
Petroleum	46	6	4	21	19	5	7	2	2	1
Natural Gas	471	462	583	480	619	405	326	385	276	146
Wood	0	0	0	0	0	0	0	0	0	0
Industrial	**1,470**	**1,511**	**1,483**	**1,488**	**1,471**	**1,450**	**1,485**	**1,521**	**1,636**	**1,923**
Coal	65	63	65	54	54	58	50	47	62	63
Petroleum	670	607	589	543	553	521	544	539	533	543
Natural Gas	607	726	706	775	741	764	787	826	947	1,196
Wood	129	115	123	116	123	106	104	110	94	120
Commercial/Institutional	**345**	**345**	**320**	**281**	**288**	**307**	**265**	**279**	**323**	**269**
Coal	0	1	0	2	3	2	3	2	2	0
Petroleum	47	44	23	14	13	18	14	15	20	15
Natural Gas	294	295	293	260	267	282	243	258	297	249
Wood	4	4	5	5	5	5	5	4	4	5
Residential	**617**	**616**	**582**	**600**	**611**	**569**	**571**	**541**	**637**	**637**
Coal	0	0	0	1	1	1	1	1	1	0
Petroleum	23	27	19	19	19	19	16	15	24	22
Natural Gas	531	522	493	520	532	484	489	487	578	579
Wood	63	67	70	60	58	65	65	38	33	36
Total	**2,950**	**2,939**	**2,971**	**2,870**	**3,007**	**2,736**	**2,654**	**2,728**	**2,873**	**2,975**

Source: EIA 1999
Note: Totals may not sum due to independent rounding.

Table 2-10: CH$_4$ and N$_2$O Emission Factors by Fuel Type and Sector (g/GJ)

Sector/Fuel Type	CH$_4$	N$_2$O
Electric Utilities		
Coal	1	1.4
Petroleum	3	0.6
Natural Gas	1	0.1
Wood	30	4.0
Industrial		
Coal	10	1.4
Petroleum	2	0.6
Natural Gas	5	0.1
Wood	30	4.0
Commercial/Institutional		
Coal	10	1.4
Petroleum	10	0.6
Natural Gas	5	0.1
Wood	300	4.0
Residential		
Coal	300	1.4
Petroleum	10	0.6
Natural Gas	5	0.1
Wood	300	4.0

Source: IPCC/UNEP/OECD/IEA 1997

CH$_4$ and N$_2$O from Mobile Source Combustion

The combustion of fuel in mobile sources results in emissions CO$_2$, CH$_4$, and N$_2$O. The methodology for estimating emissions of CO$_2$ is discussed earlier in this chapter, and involves a simple calculation based on the quantity and characteristics of the fuel combusted. The emission pathways of CH$_4$ and N$_2$O are more complex, as they depend on air-fuel mixes, combustion temperatures, fuel characteristics, and the use of pollution control equipment. For example, N$_2$O emissions are largely dependent on the catalytic processes used to control NO$_x$, CO, and hydrocarbon emissions. Methane emissions are not only determined by the methane content of the fuel, but also by the amount of uncombusted hydrocarbons passing through the engine, and the presence of pollution control technologies such as catalytic converters.

Methane and N$_2$O emissions were estimated for both highway vehicles and aviation. As highway vehicles have been extensively studied due to their significant effect on local air pollution, activity data for this source were readily available. Since emissions from non-highway sources are much less significant – and therefore less studied – the underlying activity data for modes other than aviation were not available at the state level.

Tables 2-11 and 2-12 provide CH$_4$ and N$_2$O emission estimates from mobile combustion by vehicle and fuel type in California. In 1999, total CH$_4$ emissions were 0.41 MMTCO$_2$ Eq., representing 9.1 percent of the U.S. total, while N$_2$O emissions were 6.24 MMTCO$_2$ Eq., representing 9.8 percent of the U.S. total. From 1990 to 1999, emissions of CH$_4$ and N$_2$O decreased by 24 and 9 percent, respectively. Decreased emissions were attributable to reductions in emissions from gasoline passenger cars and gasoline light-duty trucks, which constitute the majority of emissions in California. Although vehicle miles traveled (VMT) for these vehicles increased by 17 percent over this period, emissions of both N$_2$O and CH$_4$ decreased due to the implementation of stricter pollution control regulations. These regulations are more stringent than those in other states, and explain why emissions of CH$_4$ and N$_2$O from mobile sources in California have decreased more rapidly than in the United States as a whole.

Table 2-11: CH$_4$ Emissions from Mobile Source Combustion (MMTCO$_2$ Eq.)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gasoline Highway	**0.49**	**0.47**	**0.46**	**0.45**	**0.43**	**0.41**	**0.39**	**0.38**	**0.37**	**0.37**
Passenger Cars	0.25	0.25	0.24	0.23	0.22	0.21	0.21	0.20	0.20	0.19
Light-Duty Trucks	0.18	0.18	0.18	0.17	0.17	0.16	0.15	0.15	0.15	0.14
Heavy-Duty Vehicles	0.05	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
Motorcycles	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Diesel Highway	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Passenger Cars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Light-Duty Trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heavy-Duty Vehicles	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Non-Highway	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**
Aviation	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Total	**0.54**	**0.52**	**0.51**	**0.49**	**0.48**	**0.46**	**0.44**	**0.43**	**0.42**	**0.41**

Note: Totals may not sum due to independent rounding.

Table 2-12: N$_2$O Emissions from Mobile Source Combustion (MMTCO$_2$ Eq.)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gasoline Highway	**6.24**	**6.51**	**6.61**	**6.59**	**6.43**	**6.23**	**6.01**	**5.78**	**5.70**	**5.64**
Passenger Cars	3.48	3.60	3.64	3.60	3.52	3.42	3.31	3.19	3.12	3.05
Light-Duty Trucks	2.60	2.74	2.79	2.80	2.71	2.61	2.50	2.40	2.38	2.38
Heavy-Duty Vehicles	0.16	0.17	0.17	0.19	0.19	0.20	0.20	0.19	0.21	0.21
Motorcycles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Highway	**0.21**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.21**	**0.20**	**0.20**	**0.21**
Passenger Cars	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Light-Duty Trucks	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Heavy-Duty Vehicles	0.19	0.18	0.18	0.18	0.18	0.18	0.19	0.18	0.18	0.18
Non-Highway	**0.37**	**0.35**	**0.34**	**0.35**	**0.39**	**0.37**	**0.41**	**0.40**	**0.41**	**0.39**
Aviation	0.37	0.35	0.34	0.35	0.39	0.37	0.41	0.40	0.41	0.39
Total	**6.82**	**7.06**	**7.15**	**7.14**	**7.02**	**6.81**	**6.63**	**6.39**	**6.32**	**6.24**

Note: Totals may not sum due to independent rounding.

Methodology

Estimates of CH$_4$ and N$_2$O emissions were obtained by applying emission factors to activity data for each category. For highway vehicles, these data include annual VMT, age distribution, vehicle mileage accumulation, and pollution control technology type for each vehicle type. For aviation, data on energy consumption of jet fuel and aviation gasoline was used. Estimates of these gases were developed using a methodology similar to that outlined in the U.S. Inventory (EPA 2001), which is consistent with the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997).

Highway Vehicles

Methane and N$_2$O emissions from highway vehicles were estimated by determining the total VMT that can be attributed to each control technology and fuel type, and applying emission factors specific to each technology and fuel. As both new and older cars are on the road at any given time and pollution control technologies on highway vehicles have advanced dramatically since the early 1970's, it was necessary to allocate the VMT in each calendar year across 25 model years for each vehicle category. These VMT data were then allocated to control technologies based on the distribution of these technologies in each model year.

Step 1: Determine VMT by Vehicle Type, Fuel Type, and Model Year

California VMT data for gasoline and diesel highway vehicles were obtained for each vehicle type and fuel type from the California Air Resources Board's EMFAC2000 model (ARB 2000), and are presented in Table 2-13. These will be referred to as

"vehicle categories", and are divided into gasoline passenger cars (LDGV), light-duty gasoline trucks (LDGT), heavy-duty gasoline vehicles (HDGV), diesel passenger cars (LDDV), light-duty diesel trucks (LDDT), heavy-duty diesel vehicles (HDDV), and motorcycles (MC). Total VMT for each vehicle category was distributed across 25 model years according to the methodology described in the U.S. Inventory:

> "Total VMT were distributed based on the VMT distribution by vehicle age. This distribution was derived by weighting the temporally fixed age distribution of the U.S. vehicle fleet according to vehicle registrations by the average annual age-specific vehicle mileage accumulation rates of U.S. vehicles which were both obtained from EPA's Mobile6 model." (EPA 2001)

Age distribution, vehicle mileage accumulation, and the percent VMT allocated to each model year are shown in Tables 2-14, 2-15, and 2-16, respectively.

Step 2: Allocate VMT Data to Control Technology Type

California VMT by vehicle category for each model year was allocated to control technology type based on the technology distribution in each model year. This distribution is shown in Tables 2-17 for gasoline passenger cars and light-duty trucks, Table 2-18 for gasoline heavy-duty vehicles, and Table 2-19 for diesel vehicles. These technology categories are described in the U.S. Inventory as follows,

> "The categories 'Tier 0' and 'Tier 1' were substituted for the early three-way catalyst and advanced three-way catalyst categories, respectively, as defined in the Revised 1996 IPCC Guidelines. Tier 0, Tier 1, and LEV are actually U.S. emission regulations, rather than control technologies; however, each does correspond to particular combinations of control technologies and engine design. Tier 1 and its predecessor Tier 0 both apply to vehicles equipped with three-way catalysts. The introduction of 'early three-way catalysts,' and 'advance three-way catalysts' as described in the Revised 1996 IPCC Guidelines, roughly correspond to the introduction of Tier 0 and Tier 1 regulations (EPA 1998)."

Step 3: Determine the Amount of CH_4 and N_2O Emitted by Vehicle, Fuel, and Control Technology Type

Emissions of CH_4 and N_2O were calculated by multiplying emission factors specific to fuel and control technology by the total VMT allocated to each technology type. All emission factors are consistent with those used in the U.S. Inventory (EPA 2001), and are shown in Table 2-20.

Aviation

Activity data for aviation were based on California energy consumption statistics for jet fuel and aviation gasoline, as shown in Table 2-21. Emissions of CH_4 and N_2O were calculated by dividing energy consumption by the heat content of the fuel to obtain an estimate of fuel consumption (in kg), and then multiplying this value by the appropriate emission factor in IPCC/UNEP/OECD/IEA (1997). Heat contents and emission factors are displayed in Table 2-22.

Data Sources

Highway Vehicles

The California Air Resources Board provided VMT by vehicle type for 1990-1999 (ARB 2000). Age distribution and vehicle mileage accumulation for each vehicle

type was obtained from EPA's Office of Transportation and Air Quality Mobile6 model (EPA 2000). Control technology data for highway vehicles were obtained from the EPA report, *Emissions of Nitrous Oxide from Highway Mobile Sources: Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996* (EPA 1998).

The emission factors used were identical to those in the U.S. Inventory. Methane emission factors for both diesel and gasoline-fueled vehicles were obtained from IPCC/UNEP/OECD/IEA (1997), and were developed using EPA's MOBILE5a model. N_2O emission factors for gasoline-fueled passenger cars and diesel vehicles were also obtained from IPCC/UNEP/OECD/IEA (1997), while N_2O emission factors for other types of gasoline-fueled vehicles – light-duty trucks, heavy-duty vehicles, and motorcycles – were obtained from the EPA report *Emissions of Nitrous Oxide from Highway Mobile Sources: Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996* (EPA 1998).

Aviation

Estimates of energy consumption of jet fuel and aviation gasoline were obtained from EIA (1999). U.S. default emission factors for CH_4 and N_2O were obtained from the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997).

Table 2-13: Vehicle Miles Traveled for Highway Vehicles (10^6 Miles)

Year	Gasoline				Diesel		
	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles	Motorcycles	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles
1990	152,695	68,855	7,524	1,310	2,224	1,139	12,603
1991	154,404	70,912	6,738	1,315	2,064	1,184	11,970
1992	155,385	72,460	6,475	1,178	1,933	1,236	11,897
1993	156,300	75,232	6,432	1,113	1,794	1,349	11,989
1994	157,749	76,980	6,373	1,044	1,674	1,425	11,928
1995	159,344	78,691	6,183	1,024	1,554	1,542	12,106
1996	160,321	80,228	6,122	1,025	1,445	1,660	12,467
1997	161,510	81,923	5,610	786	1,328	1,765	11,774
1998	164,499	86,311	5,836	754	1,226	1,893	12,009
1999	167,513	91,016	5,907	722	1,135	1,957	12,218

Source: ARB 2000

Table 2-14: Age Distribution by Vehicle/Fuel Type for Highway Vehicles (percent)

Vehicle Age (year)	LDGV[a]	LDGT[b]	HDGV[c]	LDDV[d]	LDDT[e]	HDDV[f]	MC[g]
1	5.3%	5.8%	4.9%	5.3%	5.9%	4.2%	14.4%
2	7.1%	7.6%	8.9%	7.1%	7.4%	7.8%	16.8%
3	7.1%	7.5%	8.1%	7.1%	6.9%	7.2%	13.5%
4	7.1%	7.3%	7.4%	7.1%	6.4%	6.7%	10.9%
5	7.0%	7.1%	6.8%	7.0%	6.0%	6.2%	8.8%
6	7.0%	6.8%	6.2%	7.0%	5.6%	5.8%	7.0%
7	6.9%	6.5%	5.6%	6.9%	5.2%	5.3%	5.6%
8	6.8%	6.1%	5.1%	6.8%	4.8%	5.0%	4.5%
9	6.6%	5.7%	4.7%	6.6%	4.5%	4.6%	3.6%
10	6.3%	5.2%	4.3%	6.3%	4.2%	4.3%	2.9%
11	5.9%	4.7%	3.9%	5.9%	3.9%	4.0%	2.3%
12	5.4%	4.2%	3.6%	5.4%	3.6%	3.7%	9.7%
13	4.6%	3.6%	3.3%	4.6%	3.4%	3.4%	0.0%
14	3.6%	3.1%	3.0%	3.6%	3.2%	3.2%	0.0%
15	2.9%	2.6%	2.7%	2.9%	2.9%	2.9%	0.0%
16	2.3%	2.2%	2.5%	2.3%	2.7%	2.7%	0.0%
17	1.8%	1.8%	2.3%	1.8%	2.5%	2.5%	0.0%
18	1.4%	1.4%	2.1%	1.4%	2.4%	2.4%	0.0%
19	1.1%	1.2%	1.9%	1.1%	2.2%	2.2%	0.0%
20	0.9%	1.1%	1.7%	0.9%	2.1%	2.0%	0.0%
21	0.7%	1.1%	1.6%	0.7%	1.9%	1.9%	0.0%
22	0.6%	1.0%	1.5%	0.6%	1.8%	1.8%	0.0%
23	0.4%	1.0%	1.3%	0.4%	1.7%	1.6%	0.0%
24	0.4%	0.9%	1.2%	0.4%	1.6%	1.5%	0.0%
25	1.0%	4.6%	5.4%	1.0%	7.3%	7.2%	0.0%

[a] LDGV (gasoline passenger cars, also referred to as light-duty gas vehicles)
[b] LDGT (light-duty gas trucks)
[c] HDGV (heavy-duty gas vehicles)
[d] LDDV (diesel passenger cars, also referred to as light-duty diesel vehicles)
[e] LDDT (light-duty diesel trucks)
[f] HDDV (heavy-duty diesel vehicles)
[g] MC (motorcycles)
Note: Based on U.S. vehicle registrations

Table 2-15: Annual Age-specific Vehicle Mileage Accumulation of U.S. Vehicles (Miles)

Vehicle Age (year)	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	14,910	19,906	20,218	14,910	26,371	28,787	4,786
2	14,174	18,707	18,935	14,174	24,137	26,304	4,475
3	13,475	17,559	17,100	13,475	22,095	24,038	4,164
4	12,810	16,462	16,611	12,810	20,228	21,968	3,853
5	12,178	15,413	15,560	12,178	18,521	20,078	3,543
6	11,577	14,411	14,576	11,577	16,960	18,351	3,232
7	11,006	13,454	13,655	11,006	15,533	16,775	2,921
8	10,463	12,541	12,793	10,463	14,227	15,334	2,611
9	9,947	11,671	11,987	9,947	13,032	14,019	2,300
10	9,456	10,843	11,231	9,456	11,939	12,817	1,989
11	8,989	10,055	10,524	8,989	10,939	11,719	1,678
12	8,546	9,306	9,863	8,546	10,024	10,716	1,368
13	8,124	8,597	9,243	8,124	9,186	9,799	1,368
14	7,723	7,925	8,662	7,723	8,420	8,962	1,368
15	7,342	7,290	8,028	7,342	7,718	8,196	1,368
16	6,980	6,690	7,610	6,980	7,075	7,497	1,368
17	6,636	6,127	7,133	6,636	6,487	6,857	1,368
18	6,308	5,598	6,687	6,308	5,948	6,273	1,368
19	5,997	5,103	6,269	5,997	5,454	5,739	1,368
20	5,701	4,642	5,877	5,701	5,002	5,250	1,368
21	5,420	4,214	5,510	5,420	4,588	4,804	1,368
22	5,152	3,818	5,166	5,152	4,209	4,396	1,368
23	4,898	3,455	4,844	4,898	3,861	4,023	1,368
24	4,656	3,123	4,542	4,656	3,542	3,681	1,368
25	4,427	2,822	4,259	4,427	3,250	3,369	1,368

Table 2-16: VMT Distribution by Vehicle Age and Vehicle/Fuel Type (percent)

Vehicle Age (year)	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	7.51%	9.41%	7.89%	7.51%	11.50%	8.27%	19.39%
2	9.52%	11.56%	13.48%	9.52%	13.07%	14.00%	21.15%
3	9.05%	10.62%	11.11%	9.05%	11.15%	11.86%	15.82%
4	8.59%	9.70%	9.85%	8.59%	9.51%	10.05%	11.82%
5	8.14%	8.80%	8.43%	8.14%	8.11%	8.52%	8.77%
6	7.68%	7.92%	7.21%	7.68%	6.92%	7.22%	6.37%
7	7.22%	7.04%	6.16%	7.22%	5.90%	6.13%	4.60%
8	6.72%	6.19%	5.27%	6.72%	5.04%	5.20%	3.31%
9	6.20%	5.36%	4.51%	6.20%	4.30%	4.41%	2.33%
10	5.64%	4.57%	3.86%	5.64%	3.67%	3.74%	1.62%
11	5.03%	3.82%	3.31%	5.03%	3.13%	3.18%	1.09%
12	4.38%	3.14%	2.83%	4.38%	2.67%	2.70%	3.73%
13	3.54%	2.52%	2.42%	3.54%	2.28%	2.29%	0.00%
14	2.67%	1.99%	2.07%	2.67%	1.95%	1.94%	0.00%
15	2.01%	1.54%	1.76%	2.01%	1.66%	1.65%	0.00%
16	1.52%	1.16%	1.52%	1.52%	1.42%	1.40%	0.00%
17	1.14%	0.87%	1.30%	1.14%	1.21%	1.19%	0.00%
18	0.86%	0.64%	1.12%	0.86%	1.04%	1.01%	0.00%
19	0.65%	0.50%	0.96%	0.65%	0.89%	0.86%	0.00%
20	0.49%	0.43%	0.82%	0.49%	0.76%	0.73%	0.00%
21	0.37%	0.37%	0.70%	0.37%	0.65%	0.62%	0.00%
22	0.28%	0.32%	0.60%	0.28%	0.55%	0.53%	0.00%
23	0.21%	0.27%	0.52%	0.21%	0.47%	0.45%	0.00%
24	0.16%	0.23%	0.44%	0.16%	0.40%	0.38%	0.00%
25	0.43%	1.04%	1.85%	0.43%	1.75%	1.65%	0.00%

Note: Estimated by weighting data in Table 2-14 by data in Table 2-15.

Table 2-17: Control Technology Assignments for Gasoline Passenger Cars and Light-Duty Trucks (percent of VMT)

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1	LEV
1973-1974	100%	-	-	-	-
1975-1979	-	100%	-	-	-
1980-1981	-	15%	85%	-	-
1982	-	14%	86%	-	-
1983	-	12%	88%	-	-
1984-1991	-	-	100%	-	-
1992	-	-	60%	40%	-
1993	-	-	20%	80%	-
1994	-	-	-	90%	10%
1995	-	-	-	85%	15%
1996-1999	-	-	-	80%	20%

Note: Dash (-) indicates not applicable.

Table 2-18: Control Technology Assignments for Gasoline Heavy-Duty Vehicles (percent of VMT)

Model Years	Uncontrolled	Non-catalyst	Oxidation	Tier 0
≤1981	100%	-	-	-
1982-1984	95%	-	5%	-
1985-1986	-	95%	5%	-
1987	-	70%	15%	15%
1988-1989	-	60%	25%	15%
1990-1999	-	45%	30%	25%

Note: Dash (-) indicates not applicable.

Table 2-19: Control Technology Assignments for Diesel Highway VMT

Vehicle Type/Control Technology	Model Years
Diesel Passenger Cars and Light-Duty Trucks	
Uncontrolled	1966-1982
Moderate control	1983-1995
Advanced control	1996-1999
Heavy-Duty Diesel Vehicles	
Uncontrolled	1966-1972
Moderate control	1983-1995
Advanced control	1996-1999
Motorcycles	
Uncontrolled	1966-1995
Non-catalyst controls	1996-1999

Table 2-20: Emission Factors and "Fuel Economy" for Highway Mobile Combustion

Vehicle Type/Control Technology	N_2O (g/km)	CH_4 (g/km)	"Fuel Economy" (g CO_2/km)
Gasoline Passenger Cars			
Low Emission Vehicles	0.0176	0.025	280
Tier 1	0.0288	0.030	285
Tier 0	0.0507	0.040	298
Oxidation Catalyst	0.0322	0.070	383
Non-Catalyst	0.0103	0.120	531
Uncontrolled	0.0103	0.135	506
Gasoline Light-Duty Trucks			
Low Emission Vehicles	0.0249	0.030	396
Tier 1	0.0400	0.035	396
Tier 0	0.0846	0.070	498
Oxidation Catalyst	0.0418	0.090	498
Non-Catalyst	0.0117	0.140	601
Uncontrolled	0.0118	0.135	579
Gasoline Heavy-Duty Vehicles			
Tier 0	0.1729	0.075	1,017
Oxidation Catalyst	0.0870	0.090	1,036
Non-Catalyst Control	0.0256	0.125	1,320
Uncontrolled	0.0269	0.270	1,320
Diesel Passenger Cars			
Advanced	0.0100	0.01	237
Moderate	0.0100	0.01	248
Uncontrolled	0.0100	0.01	319
Diesel Light Trucks			
Advanced	0.0200	0.01	330
Moderate	0.0200	0.01	331
Uncontrolled	0.0200	0.01	415
Diesel Heavy-Duty Vehicles			
Advanced	0.0300	0.04	987
Moderate	0.0300	0.05	1,011
Uncontrolled	0.0300	0.06	1,097
Motorcycles			
Non-Catalyst Control	0.0042	0.13	219
Uncontrolled	0.0054	0.26	266

Source: IPCC/UNEP/OECD/IEA 1997, EPA 1998

Table 2-21: Aviation Energy Consumption by Fuel Type (BBtu)

Year	Kerosene-Based Jet Fuel	Naptha-Based Jet Fuel	Aviation Gasoline
1990	475,899	58,767	5,581
1991	464,662	43,447	5,506
1992	456,033	33,515	5,345
1993	482,909	21,819	4,134
1994	559,814	325	4,003
1995	539,923	428	4,073
1996	588,261	122	3,881
1997	584,776	48	4,222
1998	597,535	0	2,899
1999	559,477	0	4,167

Source: EIA 1999

Table 2-22: Heat Contents and Emission Factors for Aviation Fuels

Fuel Type	Heat Contents (Btu/kg)	N$_2$O (g/kg fuel)	CH$_4$ (g/kg fuel)
Jet Fuel	44.96	0.1	0.087
Aviation Gasoline	44.93	0.04	2.64

Source: Heat contents are based on data found in EIA (2000); emission factors are from IPCC/UNEP/OECD/IEA (1997).

Coal Mining

During the process of coalification, geological and biological forces convert vegetation into coal and CH$_4$ over millions of years. All coal mining results in methane emissions. The quantity of CH$_4$ emissions depends upon the amount of CH$_4$ remaining in the coal and surrounding strata when mining occurs. Deeper coal usually generates and retains more CH$_4$ than coal deposits closer to the surface. Therefore, underground mines generate the largest amount of emissions while surface mines release lower quantities of CH$_4$. Not all of the methane contained in coal is released during mining. Some CH$_4$ remains in the coal and is released during processing, storage, and transportation; these emissions are classified as post-mining emissions.

Only surface mines operated in California during in the period from 1990 through 1999. In 1990, total CH$_4$ emissions from mining in California were 0.18 MMTCO$_2$ Eq. as shown in Table 2-23. The bulk of these emissions originated from surface mining. Surface coal mining was discontinued in 1992, thus there were no emissions for mining and post-mining activities from 1993 on.

Table 2-23. Emissions from Coal Mining in California (MMTCO$_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Surface Mining	0.16	0.16	0.29	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Post-Mining Operations	0.03	0.03	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**0.18**	**0.19**	**0.34**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Note: Totals may not sum due to independent rounding.

Methodology

Methane emissions from surface mining operations in California were estimated using methods consistent with EIIP guidance (EIIP 1999). Emissions are the sum of (1) emissions that occur during mining and (2) post-mining emissions.

Methane emissions from surface mines were estimated by multiplying the total amount of surface coal production by a basin-specific methane emission factor (6.4 ft^3 CH$_4$/short ton coal), which accounts for methane liberated from the coal itself and from surrounding strata. This equation is shown below.

Emissions from surface mines (ft^3 CH$_4$) = Surface Coal Production (short tons) x 6.4 (ft^3 CH$_4$/short ton)

Methane emissions from post-mining operations in California were estimated by multiplying the total amount of surface coal production by a basin-specific post-mining methane emission factor (1.04 ft^3 CH$_4$/short ton), as shown below.

Emissions from post-mining operations (ft^3 CH$_4$) = Surface Coal Production (short tons) x 1.04 (ft^3 CH$_4$/short ton)

Data Sources

Data on coal production was obtained from the *Coal Industry Annual*, Department of Energy (1990-1999). This data was confirmed with the California Division of Mines and Tunneling (2001) and the California Department of Mines and Geology (2001). Emission factors for surface mining operations were taken from the EIIP guidance and the U.S. Inventory (EIIP 1999, EPA 2001).

Table 2-24: California Coal Production (Surface Mines)

Year	Coal Production (metric tons)
1990	55,376
1991	56,604
1992	103,386
1993	0
1994	0
1995	0
1996	0
1997	0
1998	0
1999	0
2000	0

Source: DOE 2000

Natural Gas Systems

The natural gas system is characterized by four major stages: field production, processing, transmission and storage, and distribution. Methane emissions from natural gas systems are generally related with normal operations, system upsets and routine maintenance associated with each of the four stages of the natural gas system (EPA 2001). Overall, natural gas systems emitted 2.9 MMTCO$_2$ Eq. in 2000, a slight decrease from emissions estimated in 1990 (Table 2-25). Improvements in technology and management practice, as well as retirement and replacement of old equipment, have helped reduce emissions.

Emissions from this source represented nearly 0.68 percent of gross emissions in California and 0.8 percent of Energy sector emissions.

Field production emissions occur at the gas wellhead, along the gathering pipelines, and at the field treatment facilities, in particular at dehydrators and separators. Emissions from field production accounted for approximately 2 percent of CH$_4$ emissions from natural gas systems between 1990 and 1999. During this period, emissions decreased approximately 20 percent, in line with the overall decrease in natural gas production.

During processing operations, impurities within the raw gas are removed, leaving a "pipeline quality" gas, which is injected into the transmission system. Processing plants accounted for approximately 20 percent of CH$_4$ emissions from natural gas systems in 1999. Emissions increased between 1990 and 1999 by approximately 4 percent. This increase stems from an increase in the number of processing facilities operating in the state during this period.

Natural gas transmission involves the high-pressure transport of gas across large distances from field production and processing to distribution interfaces. Fugitive emissions from reciprocating and turbine compressor stations account for the majority of emissions during this stage. Methane emissions from transmission and storage accounted for approximately 27 percent of CH_4 emissions from natural gas systems between 1990 and 1999. The emission increase in this stage was in line with transmission pipeline increase during the period.

Distribution pipelines take the high-pressure gas from the transmission system and reduce the pressure for distribution through mains and service lines to the end user. In 1999 there were approximately 93,000 miles of distribution mains, an increase of over 9,700 miles since 1990. Distribution system emissions stem mainly from fugitive losses at gate stations and non-plastic piping (cast iron and steel). The distribution system accounted for approximately 48 percent of methane emissions from natural gas systems in 1999. Between 1990 and 1999, CH_4 emissions decreased by nearly 26 percent. These reductions are due to an increase in the use of plastic piping, which has lower emissions than other types of piping.

Table 2-25: CH_4 Emissions from Natural Gas Systems (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Field Production	0.10	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.08
Processing	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.60	0.60	0.58
Transmission and Storage	0.79	0.79	0.81	0.81	0.81	0.81	0.80	0.80	0.82	0.85
Distribution	1.89	1.79	1.73	1.59	1.48	1.54	1.47	1.43	1.38	1.3
Total	**3.34**	**3.24**	**3.19**	**3.05**	**2.94**	**3.00**	**2.91**	**2.91**	**2.87**	**2.90**

Methodology

Methane emissions from the natural gas system were estimated using methodology described in the EIIP guidance (EIIP 1999):

$$CH_4\ Emissions = \sum_{i=1}^{n} \left[Activity\ Data \times EF \right]_{Field\ Production} + \sum_{i=1}^{n} \left[Activity\ Data \times EF \right]_{Processing}$$
$$+ \sum_{i=1}^{n} \left[Activity\ Data \times EF \right]_{Transmission\ /\ Storage} + \sum_{i=1}^{n} \left[Activity\ Data \times EF \right]_{Distribution}$$

Where: Activity Data = Statistics on gas production, number of wells, miles of various pipe, and other statistics that characterize the Californian natural gas system infrastructure and operations.
EF = Emission Factor (metric tons CH_4/unit)

California's natural gas system was described by defining key activity parameters for each of the four major stages (field production, processing, transmission and storage, and distribution). Emissions for each stage were estimated by multiplying the activity parameters by their associated emission factors, and summing all the sources for each stage. Total methane emissions were estimated by adding the emission estimates for each stage.

Data Sources

The activity data compiled for each of the four major stages includes: number of associated/non-associated wells (CDC 2001a); number of offshore platforms (CDC 2001a); miles of gathering, transmission, distribution and services pipeline (DOT 2001); number of processing facilities (O&J 1997-2001); number of transmission facilities (EIA 2001); and number of storage fields (CDC 2001b).

Petroleum Systems

The petroleum system is characterized by three major stages: field production, transportation, and refining. Methane emissions from petroleum systems generally stem from fugitive emissions, vented emissions, fuel combustion emissions, and from operational upsets (EPA 2001). Total methane emissions from petroleum systems in 2000 were estimated to be 0.35 MMTCO$_2$ Eq. Since 1990, emissions have gradually declined due to a reduction in state-level oil production (see Table 2-6).

Emissions from petroleum systems in California accounted for 0.08 percent of gross state emissions and 0.10 percent of Energy sector emissions.

Field production operations accounted for the majority (78 percent) of total methane emissions from petroleum systems. Vented methane from oil wells, and related processing equipment account for the majority of emissions associated with oil production. Between 1990 and 1999, methane emissions decreased by approximately 10 percent. This is attributable to a decline in the quantity of crude oil produced within the state during this period.

Crude oil transportation activities, which include venting from tanks and loading operations from marine vessels, accounted for approximately 6 percent of total methane emissions from petroleum systems.

Crude oil refining operations accounted for approximately 17 percent of total methane emissions from petroleum systems. Vented emissions from refinery blowdowns are the primary contributor to emissions, while fugitive losses stemming from system leaks in the fuel gas line account for the remainder. Refining emissions decreased by approximately 14 percent between 1990 and 1999. This reduction is attributable to the decline in crude oil production within the state.

Table 2-26: CH$_4$ Emissions from Petroleum Systems (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Field Production	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.30	0.29	0.28
Transportation	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Refining	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total	**0.40**	**0.40**	**0.39**	**0.39**	**0.39**	**0.39**	**0.39**	**0.38**	**0.38**	**0.36**

Methodology

Methane emissions from the petroleum system were estimated using methodology described in the EIIP guidance (EIIP 1999):

$$CH_4 \ Emissions = \sum_{i=1}^{n} \left[Activity \ Data \times EF \right]_{Field \ Production} + \sum_{i=1}^{n} \left[Activity \ Data \times EF \right]_{Transportation}$$

$$+ \sum_{i=1}^{n} \left[Activity \ Data \times EF \right]_{Refining}$$

Where: Activity Data = Statistics on oil production, amount of venting/flaring, quantity of oil tankered, and the quantity of oil refined.
EF = Emission Factor (lbs. CH_4/MMBtu)

California's petroleum system was described by defining key activity parameters for each of the three major stages (field production, transportation and refining). Emissions for each stage were estimated by multiplying the activity parameters by their associated emission factors, and summing all the sources for each stage. Total methane emissions were estimated by adding the emission estimates for each stage.

State-level tankered information was only available for 1993. Thus, the quantity transported to/from refineries was assumed to remain constant from 1990 through 1999. Table 2-27 details the emission factors used for each activity parameter.

Table 2-27: Petroleum System Activity Data and Emission Factors

Sector/Activity Data	Emission Factor (lbs. CH_4/MMBtu)
Field Production	
Oil Production	0.0062
Vented/Flared Emissions	0.0099
Transportation	
Oil Tankered	0.0017
Refining	
Oil Refined	0.0017

Source: EIIP 1999

Data Sources

Activity data for field production includes, total oil production (CDC 2001), and the total vented and flared emissions (EIA 2001). Transportation activity data, in particular, the total quantity of oil tankered, was obtained from California Energy Commission, *1995 Fuels Report* (Commission 1995). The total oil refined in California was obtained from the Commission, *Monthly California Refining Industry Operating Report* (Commission 1997-2000, Commission 2001).

International Bunker Fuels

According to the guidance for national- and state-level inventories (IPCC/UNEP/OECD/IEA 1997 and EIIP 1999, respectively), emissions from international transportation activities, or bunker fuels, are to be estimated but not attributed to the national- or state-level totals. Although California has both aviation and marine fuels that fall under this category, only marine fuels were estimated due to data limitations. This section explains the approach used to quantify CO_2, CH_4, and N_2O emissions from fuels consumed by marine vessels leaving the ports of San Diego, Los Angeles, and San Francisco for other countries. In the national inventory, fuel consumed by this source category is deducted from the total fossil fuels consumed in the state. Due to the quality and availability of data on bunker fuels, emissions from this source are not subtracted out of the emissions from fossil fuel combustion. Instead, they are estimated and emissions are not included in any energy sector totals. [*This section is likely to be revised, pending results of Guido's inquiries regarding fuel already in vessels and/or purchasing data.*]

Greenhouse gas emissions from international bunker fuels attributed to California totaled 10.68 MMTCO$_2$ Eq. in 1999 (see Table 2-28). These emissions consisted primarily of CO_2 (10.58 MMTCO$_2$ Eq.), but also included CH_4 (0.02 MMTCO$_2$ Eq.) and N_2O (0.08 MMTCO$_2$ Eq.). California emissions from marine bunker fuels in 1999 represented about 23 percent of U.S. emissions from this source.

Emissions of CO_2, CH_4, and N_2O decreased by approximately 52 percent between 1991 and 1993, and remained at approximately this level through 1999, resulting in an overall trend of declining emissions. As a result, this decrease is more drastic than the slight decline on the national level during this time period.

Table 2-28: Emissions from International Bunker Fuels, 1990-1999 (MMTCO$_2$ Eq.)

Gas/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO$_2$	**21.76**	**22.75**	**12.58**	**10.50**	**9.05**	**10.77**	**10.42**	**10.71**	**9.83**	**10.58**
Distillate Fuel Oil	1.32	1.10	0.78	0.84	0.51	0.65	0.43	0.52	0.67	0.37
Residual Fuel Oil	20.44	21.66	11.80	9.66	8.54	10.12	9.99	10.19	9.16	10.21
CH$_4$	**0.04**	**0.05**	**0.03**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Distillate Fuel Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residual Fuel Oil	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
N$_2$O	**0.17**	**0.17**	**0.10**	**0.08**	**0.07**	**0.08**	**0.08**	**0.08**	**0.07**	**0.08**
Distillate Fuel Oil	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00
Residual Fuel Oil	0.16	0.16	0.09	0.07	0.06	0.08	0.08	0.08	0.07	0.08
Total	**21.97**	**22.97**	**12.70**	**10.60**	**9.13**	**10.88**	**10.52**	**10.81**	**9.93**	**10.68**

Note: Totals may not sum due to independent rounding.

Methodology

Emissions of CO_2 from international bunker fuels were estimated using the same basic methodology as was used to estimate emissions from consumption of all fossil fuels in the section, "CO_2 from Fossil Fuel Combustion." Marine bunker fuel consumption of

distillate diesel and residual fuel were obtained (in barrels) and multiplied by the heat content coefficient of each fuel to determine the energy consumed. Next, the appropriate carbon content coefficients and fraction oxidized factors were applied to estimate carbon emissions. Emissions of CH_4 and N_2O were estimated by multiplying IPCC emission factors by fuel consumption data. Emissions from aviation bunker fuels were not estimated because activity data were not available at the state level.

Data Sources

Distillate diesel and residual fuel oil consumption data from passenger and freight marine vessels departing from California ports (see Table 2-29 were obtained from the Foreign Trade Division of the U.S. Department of Commerce's Bureau of the Census (DOC 1991 through 2000). Carbon content coefficients were taken from chapter 1 of the EIIP guidance (EIIP 1999). Emission factors for CH_4 and N_2O and the fraction of carbon oxidized during combustion were obtained from the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997). Heat content coefficients were obtained from Annex A of the *Annual Energy Review 2000* (EIA 2000). Relevant coefficients and factors are shown in Table 2-30.

Table 2-29: International Bunker Fuel Consumption, 1990-1999 (Million Bbl)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Distillate Fuel Oil	3.14	2.60	1.84	1.99	1.20	1.54	1.01	1.22	1.59	0.87
Residual Fuel Oil	41.65	44.14	24.05	19.68	17.41	20.63	20.36	20.77	18.67	20.82
Total	**44.79**	**46.74**	**25.90**	**21.67**	**18.61**	**22.18**	**21.37**	**22.00**	**20.27**	**21.69**

Source: DOC 1991 through 2000

Table 2-30: Relevant Coefficients and Factors

Fuel Type	Heat Content (MMBtu/barrel)	Carbon Content (lbs C/MMBtu)	Fraction Oxidized	CH_4 Emission Factor (g/kg)	N_2O Emission Factor (g/kg)
Distillate Fuel Oil	5.825	44.0	0.99	0.03	0.08
Residual Fuel Oil	6.287	47.4	0.99	0.03	0.08

Sources: EIIP 1999, EPA 2001, EIA 2000, IPCC/UNEP/OECD/IEA 1997

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Chapter 3

Industrial Processes

A large number of processes in the industrial sector contribute greenhouse gas emissions to the atmosphere. These emissions result from non-energy related industrial activities, such as process related chemical reactions, or through the direct use of man-made gaseous compounds. Carbon dioxide (CO_2) is emitted from numerous industrial processes, including cement production, lime production, limestone and dolomite consumption, soda ash production and consumption, and CO_2 production. Nitric acid production releases nitrous oxide (N_2O), while the substitution of ozone depleting substances, semiconductor manufacturing, and electric utilities emit man-made fluorinated greenhouse gases, such as sulfur hexafluoride (SF_6), and hydrofluorocarbons (HFCs).

In 1999, industrial processes in California emitted 16.2 million metric tons of carbon dioxide equivalent (MMTCO$_2$ Eq.) (Table 3-1). These emissions represented 7 percent of the U.S. greenhouse gas emissions from industrial processes, and 4 percent of California's gross greenhouse gas emissions. Carbon dioxide emissions from industrial processes in 1999 were 6.2 MMTCO$_2$ Eq. The majority of these emissions, nearly 89 percent, were generated from the cement production sector. Nitrous oxide emissions from nitric acid production in 1999 were estimated at 0.3 MMTCO$_2$ Eq. Combined emissions of HFCs and SF_6 in 1999 accounted for 9.70 MMTCO$_2$ Eq., approximately 60 percent of sectoral emissions. Overall, emissions from industrial process increased by 105 percent from 1990 to 1999. The primary contributor to this increase has been the substitution of ozone depleting substances, which increased its contribution of the total industrial process emissions from less than 2 percent in 1990 to 43 percent in 1999.

Table 3-1: Emissions from Industrial Processes (MMTCO$_2$ Eq.)

Fuel/End-Use Sector	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO2	**5.30**	**4.90**	**4.69**	**4.74**	**5.32**	**5.46**	**5.64**	**5.79**	**5.86**	**6.24**
Cement Production	4.62	4.26	4.07	4.18	4.75	4.81	4.97	5.12	5.19	5.55
Lime Production	0.25	0.22	0.20	0.15	0.16	0.18	0.16	0.16	0.15	0.14
Limestone and Dolomite Consumption	0.14	0.13	0.12	0.11	0.12	0.16	0.18	0.18	0.19	0.20
Soda Ash Production and Consumption	0.22	0.21	0.21	0.21	0.21	0.22	0.21	0.22	0.22	0.21
CO_2 Consumption	0.07	0.08	0.08	0.08	0.08	0.09	0.11	0.12	0.12	0.13
N$_2$O	**0.53**	**0.52**	**0.56**	**0.38**	**0.38**	**0.49**	**0.30**	**0.30**	**0.28**	**0.28**
Nitric Acid Production	0.53	0.52	0.56	0.38	0.38	0.49	0.30	0.30	0.28	0.28
HFCs and SF$_6$	**2.07**	**2.09**	**2.29**	**2.84**	**3.54**	**5.43**	**6.81**	**7.87**	**8.73**	**9.70**
Substitution of Ozone Depleting Substances	0.12	0.10	0.19	0.65	1.23	2.94	4.15	5.15	6.10	7.00
Semiconductor Manufacture	0.36	0.36	0.36	0.46	0.52	0.67	0.86	0.86	0.84	0.84
Electric Utilities	1.60	1.63	1.74	1.74	1.80	1.81	1.81	1.87	1.80	1.87
Total	**7.90**	**7.50**	**7.53**	**7.96**	**9.25**	**11.37**	**12.75**	**13.97**	**14.87**	**16.22**

Note: Totals may not sum due to independent rounding.

Cement Production

Cement manufacture is both an energy-intensive and a raw material-intensive process. Although CO_2 is a by-product of both processes, only the manufacturing process will be considered below as emissions related to energy consumption are examined in the "Energy" chapter.

Carbon dioxide is the result of a chemical conversion process used in the production of clinker, which in turn is a component of cement. During this process, limestone ($CaCO_3$) is heated to high temperatures in a kiln to form lime (calcium oxide or CaO). The simplified stoichiometric relationships is as follows:

$$CaCO_3 + heat \rightarrow CaO + CO_2$$
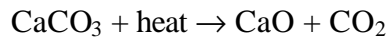
After heating, the clinker is then allowed to cool and mixed with small amounts of gypsum to produce Portland cement.

Table 3-2 presents historical CO_2 emissions from cement manufacturing from 1990 to 1999. In 1999, total CO_2 emissions from cement manufacturing in California were 5.55 MMTCO$_2$ Eq. While emissions decreased in the period 1990-1992 due to a decrease in production, they have thereafter shown a consistent upward trend throughout the period as clinker production in California increased. In 1999, California accounted for approximately 14 percent of national greenhouse gas emissions from cement production. These emissions represented approximately 1 percent of California's gross emissions.

Table 3-2: Emissions from Cement Production (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Cement Production	4.62	4.26	4.07	4.18	4.75	4.81	4.97	5.12	5.19	5.55

Methodology

Estimates of state-level CO_2 emissions from cement production were based on the following equation presented in *EIIP Volume VIII: Estimating Greenhouse Gas Emissions* (EIIP 1999):

$$California\ CO_2\ Emissions = (State\ Clinker\ Production \times CaO\ Content_{(\%)} \times 0.785)$$
$$\times CKD\ Correction\ Factor$$

The quantity of clinker produced in California was multiplied by the percent lime (CaO) content of the clinker. The default CaO content is 65 percent (IPCC 2000). To obtain the total metric tons of CO_2 emitted, multiply the quantity of CaO by its corresponding CO_2/CaO stoichiometric ratio (i.e., the molecular weight of CO_2 (44g)/molecular weight of CaO (56g) = 0.785).

Carbon dioxide emissions may also be emitted from cement kiln dust (CKD) that is not recycled to the production process. The CKD is largely a mix of calcinated and uncalcinated raw materials and clinker, and accounts for the portion of materials that does not become part of the clinker, and is lost to the system. To account for CO_2 emissions emitted from CKD, IPCC recommends that these additional CKD CO_2 emissions should

be estimated as 2 percent of the CO_2 emissions from clinker production (IPCC 2000). Hence, multiply the total metric tons of CO_2 emitted during clinker production by the CKD correction factor of 1.02.

Data Sources

The activity data for clinker production were obtained from U.S. Geological Survey (USGS), *Minerals Yearbook: Cement* (USGS 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, and 2000). The lime content of clinker, as well as, the CKD correction factor were obtained from the IPCC *Good Practice Guidance* (IPCC 2000).

Table 3-3: Annual Clinker Production (10^3 Metric Tons)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Clinker Production	8,874	8,178	7,819	8,024	9,123	9,227	9,543	9,824	9,964	10,645

Source: USGS 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, and 2000

Lime Production

Lime is used in a wide variety of applications that include steelmaking, construction, pulp and paper manufacturing, and sewage treatment. Lime production involves three main stages: stone preparation, calcination, and hydration. Carbon dioxide is emitted during the calcination stage when limestone is heated in a kiln to produce CaO and CO_2. Carbon dioxide is a by-product and is usually released into the atmosphere although some may be recovered at some facilities for use in other processes such as sugar refining or precipitated calcium carbonate production.

Table 3-4 presents emissions from lime production in California from 1990 to 1999. In 1999, total CO_2 emissions from lime production were 0.14 $MMTCO_2$ Eq. Since 1990, emissions have gradually declined due to a reduction in state-level lime production. In 1999, CO_2 emissions from state-level lime production accounted for approximately 1 percent of national CO_2 emissions from lime manufacture.

Table 3-4: Emissions from Lime Production ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Lime Production	0.25	0.22	0.20	0.15	0.16	0.18	0.16	0.16	0.15	0.14

Methodology

Estimates of state-level CO_2 emissions from lime manufacturing were based on the following equation presented in the EIIP guidance (EIIP 1999):

$$CO2\ Emissions = State\ Lime\ Production \times 0.785$$

To obtain the total metric tons of CO_2 emitted, multiply the quantity of lime (CaO) produced by its respective CO_2/CaO stoichiometric ratio. The CO_2/CaO stoichiometric ratio: molecular weight of CO_2 (44g)/molecular weight of CaO (56g) = 0.785.

Data Sources

Lime production data for 1990 through 1999 (see Table 3-5) was obtained from the California Department of Conservation, Division of Mines and Geology (CDC 2001).

Table 3-5: Lime Production (metric tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Lime Production	313,191	278,695	254,184	193,000	203,166	228,221	207,886	199,716	185,191	181,560

Source: CDC 2001

Limestone and Dolomite Consumption

Limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) are basic raw materials used by a variety of industries, including the metallurgy, chemical, and construction industries. Carbon dioxide emissions from limestone and dolomite consumption specifically occur when the compounds are used as a flux or purifier in metallurgical furnaces, as a raw material in glass making, or as a sorbent in flue gas desulfurization (FGD) systems (EPA 2001). Limestone and dolomite are collectively referred to as limestone by the industry, and intermediate compounds are seldom distinguished (EPA 2001).

As shown in Table 3-6, emissions from this sector declined between 1990 and 1993 from 0.14 to 0.11 MMTCO$_2$ Eq., reflecting a decline in crushed stone consumption throughout the United States. Since 1993, emissions have steadily increased. In 1999, CO_2 emissions from limestone and dolomite production were 0.20 MMTCO$_2$ Eq., representing an 82 percent increase over 1993 emissions. This increase reflects an upward trend in crushed stone consumption at the national level. In 1999, state-level emissions from this source accounted for 2 percent of the national limestone and dolomite consumption emissions, and just 0.05 percent of gross state emissions.

Table 3-6: Emissions from Limestone and Dolomite Production (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Limestone and Dolomite Production	0.14	0.13	0.12	0.11	0.12	0.16	0.18	0.18	0.19	0.20

Methodology

State-level data for limestone and dolomite consumption within metallurgical furnaces, glass making and FGD systems were not available, as state consumption data for limestone and dolomite include other activities, such as construction, that do not produce CO_2 emissions.

In order to obtain CO_2 emissions from limestone and dolomite consumption in California, national emissions from limestone and dolomite consumption were multiplied by the ratio of California's limestone and dolomite consumption for all industrial activities to the national consumption for all industrial activities. It was assumed that the ratio would be consistent with the use of limestone and dolomite for CO_2-producing activities at the state level.

Data Sources

National CO_2 emissions from limestone and dolomite consumption were obtained from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001). National and California state limestone and dolomite consumption data were obtained from the U.S. Geological Survey (USGS), *Minerals Yearbook: Annual Crushed Stone Reports* (USGS 1994, 1995, 1996, 1997, 1998, 1999, and 2000).

Soda Ash Production and Consumption

Soda ash (Na_2CO_3) is an alkaline substance also known as sodium carbonate. It is produced on a commercial scale as it is a raw material in various industrial processes and as well as in consumer products that include glass, soap, detergents as well as paper and food.

Only two forms of soda ash are produced worldwide - natural soda ash and synthetic soda ash. The United States, the world's largest soda ash-producing country, only produces natural soda ash and all production occurs in California and Wyoming.

The soda ash production process in California employs sodium carbonate-bearing brines. These brines are treated with CO_2 in carbonation towers. As the sodium carbonate is converted into a precipitate of sodium bicarbonate, it is then calcined back into sodium carbonate. Although CO_2 is generated as a byproduct of the reaction, it is captured and recycled and therefore no CO_2 is emitted as a result of the process (EIIP 1999). Carbon dioxide is emitted, however, when soda ash is consumed.

Table 3-7 presents CO_2 emissions from soda ash manufacturing in California from 1990 through 1999. Emissions from soda ash manufacturing in California stayed relatively flat during the period, alternating between 0.22 and 0.21 $MMTCO_2$ Eq. In 1999, emissions from soda ash production were 0.05 percent of both gross emissions in California and national emissions from this source.

Table 3-7: Emissions from Soda Ash Consumption (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Soda Ash Production	0.22	0.21	0.21	0.21	0.21	0.22	0.21	0.22	0.22	0.21

Methodology

Estimates of state-level CO_2 emissions from soda ash consumption were based on the following equation presented in the EIIP guidance (EIIP 1999):

$$CO_2 \; Emissions = \; State \; Soda \; Ash \; Consumption \times \; EF$$

Where, EF = CO_2 Emission Factor (0.415 tons CO_2/ton soda ash).

Per U.S. Geological Surveys, *Mineral Yearbooks: Soda Ash Annual Report* the primary national consumers of soda ash are glass manufacture (50 percent), chemicals (27 percent) and soap manufacture (11 percent) (USGS 2001). Since limited consumption data exists for the state of California, Standard Industrial Classifications (SIC) annual payroll data for California and total U.S. were compared for the glass and

soap manufacturing industries. Chemical industry payroll data were assumed to mirror both glass and soap industry data. The ratios of state to national annual payrolls for the associated industries were used to apportion soda ash consumption from the national to state level.

In order to obtain CO_2 emissions from soda ash consumption in California, the soda ash consumption was multiplied by an emission factor, 0.415 tons CO_2/ton soda ash.

Data Sources

National soda ash consumption data were obtained from U.S. Geological Surveys, *Mineral Yearbooks: Soda Ash Annual Report*, (USGS 1994, 1995, 1996, 1997, 1998, 1999, and 2000). National and California payroll data for the glass and soap manufacturing industries were obtained from U.S. Census Bureau, *Annual Survey of Manufacturers* (U.S. CB 1996). SIC codes for glass manufacturing are 321 and 322, while for soap manufacturing it is 284.

The soda ash consumption emission factor was taken from the EIIP guidelines (EIIP 1999).

Carbon Dioxide Consumption

Carbon dioxide is produced from natural wells, as a by-product from chemical production or by means of separation from crude oil and natural gas. This gas is also used for a variety of applications that include enhanced oil recovery, chemical production as well as food processing and carbonated beverages. Carbon dioxide produced from fossil fuel consumption, that is, CO_2 generated from chemical production processes that use hydrocarbon as a raw material (e.g. ammonia production), are accounted for in the "Energy" chapter. Furthermore, CO_2 used in enhanced oil recovery is considered as sequestered, as it is re-injected into the ground and leak rates are uncertain.

Table 3-8 presents emissions from CO_2 consumption in California from 1990 to 1999. In 1999, CO_2 emissions from CO_2 consumption were 0.13 MMTCO$_2$ Eq. Emissions from the sector have shown a consistent upward trend in line with the CO_2 production capacity at the national and state levels. In 1999, 8 percent of national emissions from CO_2 consumption were attributable to California. These emissions represent 0.03 percent of California's gross greenhouse gas emissions.

Table 3-8: Emissions from CO_2 Consumption (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO_2 Consumption	0.07	0.08	0.08	0.08	0.08	0.09	0.11	0.12	0.12	0.13

Methodology

Carbon dioxide emission estimates were based on the assumption that, except for enhanced oil recovery that is considered sequestered, all end-use applications release 100 percent of the CO_2 manufactured. Because industries associated with CO_2 consumption are widespread throughout the United States, state emissions were estimated by pro-rating national emissions based on state CO_2 production capacity. Estimates of state-level emissions from CO_2 consumption were based on the following equation:

$$State\ CO_2\ Emissions = National\ CO_2\ Emissions \times State\ Production\ Capacity$$
$$\div\ National\ Production\ Capacity$$

In order to obtain CO_2 emissions from carbon dioxide consumption in California, national emissions from CO_2 consumption were multiplied by the ratio of California's CO_2 production capacity to the national production capacity. Production capacity data were only available for the years 1990, 1992, 1993, 1995, 1996 and 1998. For years 1991, 1994 and 1997, CO_2 emissions were estimated through interpolation. For 1999, national and state production capacity was assumed to remain constant at 1998 levels.

Data Sources

National CO_2 emissions data were obtained from the U.S. Inventory (EPA 2001), as shown in Table 3-9. National and state-level CO_2 production capacity data were obtained from the *Directory of Chemical Producers* (SRI 1990, 1992, 1993, 1995, 1996, 1998).

Table 3-9: National CO_2 Emissions from CO_2 Consumption (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO$_2$	0.80	0.84	0.88	0.91	0.90	0.97	1.14	1.29	1.41	1.57

Source: EPA 2001

Nitric Acid Production

Nitrous oxide is generated as a by-product during the production of nitric acid (HNO_3). Nitric acid is mainly used to produce synthetic commercial fertilizer and is also a component of adipic acid and explosives. Small quantities of nitric acid are also used in stainless steel pickling, metal etching, rocket propellants, and nuclear fuel processing.

Nitric acid production usually occurs through the catalytic oxidation of ammonia, where N_2O is released into the atmosphere as a by-product of the process (EPA 2001). Although the nitric acid industry regulates emissions of NO and NO_2, only non-selective catalytic reduction (NSCR) technologies are also capable of reducing N_2O emissions. Modern plants typically do not install NSCR technologies due to their high-energy costs and gas temperatures.

Table 3-10 presents the emissions from this sector in California from 1990 to 1999. In 1999, emissions from nitric acid production were 0.28 MMTCO$_2$ Eq. Between 1990 and 1999 emissions have fluctuated inline with California's production levels. By 1999, emissions were approximately 47 percent lower than 1990 levels. In 1999, state-level emissions accounted for approximately 1 percent of national emissions from this source.

Table 3-10: Emissions from Nitric Acid Production (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Nitric Acid Production	0.53	0.52	0.56	0.38	0.38	0.49	0.30	0.30	0.28	0.28

Methodology

Nitrous oxide emissions from nitric acid production were estimated using the following equation taken from the EIIP guidance (EIIP 1999):

$$N_2O\ Emissions = State\ Nitric\ Acid\ Production \times EF$$

Where, EF = N_2O Emission Factor (Default = 0.008 tons N_2O/ton Nitric Acid Produced)

In order to obtain state-level nitric acid production in California, national nitric acid production levels were multiplied by the ratio of California's nitric acid production capacity to the national production capacity. Production capacity data were only available for the years 1990, 1992, 1993, 1995, 1996 and 1998. For years 1991, 1994 and 1997, N_2O emissions were estimated through interpolation. For 1999, national and state production capacity was assumed to remain constant at 1998 levels. Estimated state nitric acid production was then multiplied by a default emission factor to determine state-level N_2O emissions.

Data Sources

National nitric acid production data was obtained from the U.S. Inventory (EPA 2001). National and state-level nitric production capacity data were obtained from the *Directory of Chemical Producers* (SRI 1990, 1992, 1993, 1995, 1996, 1998). The N_2O emission factor was based on the IPCC guideline default (IPCC 2000).

Substitution of Ozone-Depleting Substances

Ozone-depleting substances (ODSs) are being phased out under the terms of the Montreal Protocol and the Clean Air Act Amendments of 1990, and many of the substances approved to replace them, including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), are greenhouse gases. Historically, ozone depleting substances (chlorofluorocarbons (CFCs), halons, carbon tetrachloride, hydrochlorofluorocarbons (HCFCs), and methyl chloroform) have been used industrial applications such as refrigeration and air conditioning equipment, solvent cleaning, foam production, sterilization, fire extinguishing, and aerosols. Hydrofluorocarbons and PFCs are now being used in most of these applications.

Table 3-11: ODS Substitute Emission Estimates (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
HFC-23	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04
HFC-32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HFC-125	0.00	0.00	0.08	0.17	0.10	0.16	0.23	0.30	0.38	0.45
HFC-134a	0.09	0.09	0.10	0.46	1.01	2.29	3.01	3.73	4.29	4.87
HFC-143a	0.00	0.00	0.00	0.01	0.02	0.05	0.10	0.16	0.23	0.32
HFC-236fa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.17
CF$_4$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Others[a]	0.03	0.01	0.01	0.01	0.10	0.44	0.80	0.93	1.08	1.17
Total	**0.12**	**0.10**	**0.19**	**0.65**	**1.23**	**2.94**	**4.15**	**5.15**	**6.10**	**7.00**

Source: EPA 2001
[a]Others include HFC-152a, HFC-227ea, HFC-4310mee, and PFC/PFPEs, the latter being a proxy for a diverse collection of PFCs and perfluoropolyethers (PFPEs) employed for solvent applications. For estimating purposes, the global warming potential (GWP) value used for PFC/PFPEs was based upon C_6F_{14}. Note: Totals may not sum due to independent rounding.

The trends of ODS substitute emissions in California echo the trends that have been seen on a national level. In the early 1990s, ODS substitute emissions primarily consisted of HFC-134a from refrigeration and motor vehicle air conditioning end-uses. By the mid-1990s, other end-uses, such as foam blowing, aerosol propellants, solvents and sterilization, began using a larger variety of high GWP substitutes. By 1995, ODS substitutes for halons entered widespread use in the United States as halon production was phased-out.

The use and subsequent emissions of HFCs and PFCs as ODS substitutes has been increasing from small amounts in 1990 to 7.00 MMTCO$_2$ Eq. in 1999. Although the absolute magnitude of emissions from ODS substitutes is relatively small (2 percent of gross California emissions in 1999), its growth has been faster than any other sector. The increase has been driven by efforts to phase-out ODSs in the United States. This trend is expected to continue, although improvements in the technologies associated with the use of these gases may help to offset further increases in these emissions.

Methodology

The EIIP guidelines for estimating emissions from this source instruct states to disaggregate national estimates of ODS substitute emissions by applying a ratio of state to national population to the national emission estimates (EIIP 1999). Thus, California ODS substitute emissions for the years 1990 through 1999 were estimated based on the following equation:

California ODS substitute emissions = U.S. ODS substitute emissions ×
(California population/National
population)

The EPA estimates ODS substitute emissions using a detailed vintaging model of ODS-containing equipment and products. The U.S. Inventory describes the vintaging model as follows:

"The name of the model refers to the fact that the model tracks the use and emissions of various compounds for the annual "vintages" of new equipment that enter service in each end-use. This vintaging model predicts ODS and ODS substitute use in the United States based on modeled estimates of the quantity of equipment or products sold each year containing these chemicals and the amount of the chemical required to manufacture and/or maintain equipment and products over time. Emissions for each end-use are estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as they leak over time. By aggregating the data for more than 40 different end-uses, the model produces estimates of annual use and emissions of each compound." (EPA 2001)

Data Sources

Two primary data sources were used to develop estimates of ODS substitute emissions. National emission estimates of ODS substitutes (see Table 3-12) were obtained from the U.S. Inventory (EPA 2001). National and state population estimates, shown in Table 3-13, were obtained from the U.S. Census Bureau (2000) and the California State Department of Finance (2001), respectively.

Table 3-12: National Emissions of ODS Substitutes (MMTCO$_2$Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
HFC-23	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.12	0.20	0.29
HFC-32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
HFC-125	0.00	0.00	0.66	1.35	0.84	1.34	1.89	2.49	3.13	3.61
HFC-134a	0.73	0.73	0.81	3.75	8.17	18.65	24.65	30.52	34.91	39.44
HFC-143a	0.00	0.00	0.00	0.05	0.19	0.42	0.79	1.27	1.85	2.57
HFC-236fa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.75	1.34
CF$_4$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Others[a]	0.21	0.11	0.04	0.10	0.77	3.57	6.58	7.64	8.80	9.44
Total	**0.94**	**0.84**	**1.52**	**5.24**	**9.97**	**24.00**	**33.98**	**42.14**	**49.65**	**56.71**

Source: EPA 2001
[a]Others include HFC-152a, HFC-227ea, HFC-4310mee, and PFC/PFPEs, the latter being a proxy for a diverse collection of PFCs and perfluoropolyethers (PFPEs) employed for solvent applications. For estimating purposes, the GWP value used for PFC/PFPEs was based upon C$_6$F$_{14}$.
Note: Totals may not sum due to independent rounding.

Table 3-13: Ratio of California to U.S. Population

Year	CA Population	U.S. Population	Ratio
1990	30,595,770	249,464,396	0.12
1991	30,945,000	252,153,092	0.12
1992	31,478,000	255,029,699	0.12
1993	31,858,000	257,782,608	0.12
1994	32,075,000	260,327,021	0.12
1995	32,223,000	262,803,276	0.12
1996	32,396,000	265,228,572	0.12
1997	32,743,000	267,783,607	0.12
1998	33,186,000	270,248,003	0.12
1999	33,660,000	272,690,813	0.12
2000	34,207,000	281,421,906	0.12

Semiconductor Manufacturing

Two processes within the course of semiconductor manufacturing use and emit fluorinated greenhouse gases, such as trifluoromethane (HFC-23), perfluoromethane (CF$_4$), perfluoroethane (C$_2$F$_6$), and sulfur hexafluoride (SF$_6$). The exact combination of compounds is specific to the process employed. Plasma etching uses fluorinated compounds that selectively remove substrate material from the silicon to create pathways. Chemical vapor deposition chambers, which are used for used for depositing materials that will act as insulators and wires, are periodically cleaned using PFCs and other gases. A portion of the PFCs flowing into the chemical vapor deposition chamber flows through without reacting with the chamber and is emitted to the atmosphere, unless emission abatement technologies are used. Both processes also emit reacted fluorinated compounds. Because the exact combination of compounds used and the resulting reacted or unreacted compounds emitted are difficult to estimate on an individual basis, emissions are not estimated by gas, but are provided as weighted average total emissions in Table 3-14.

Table 3-14: Emissions of Fluorinated Compounds from Semiconductor Manufacturing (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Semiconductor Manufacturing	0.36	0.36	0.36	0.46	0.52	0.67	0.86	0.86	0.84	0.84

Emissions from semiconductor manufacturing grew from 0.36 MMTCO$_2$ Eq. in 1990 to 0.84 MMTCO$_2$ Eq in 1999, representing an increase of over 133 percent. This rapid growth is the result of not only the rapid growth in the semiconductor industry, but also the increasing complexity of the semiconductor products, which leads to greater use of PFCs per semiconductor chip. However, the growth in emissions is slowing down, and emissions from this sector have declined slightly since 1997. As reported in the U.S. Inventory (EPA 2001), this is due to the implementation of PFC emission reduction methods, which are expected to lead to even greater improvements over the next decade. Emissions from this sector were responsible for 0.2 percent of gross California emissions in 1999.

Methodology

The EIIP guidelines do not provide a method for estimating state-level emissions from this source. However, in an effort to make the California greenhouse gas inventory as comprehensive as possible, semiconductor manufacturing emissions have been estimated by apportioning national emissions from semiconductor manufacturing on the basis of population. Thus, California semiconductor manufacturing emissions for the years 1990 through 1999 were estimated based on the following equation:

California semiconductor manufacturing emissions =
U.S. semiconductor manufacturing emissions $\times$ (California population/National population)

The EPA estimates semiconductor manufacturing emissions using a combination of modeling methods and data provided by semiconductor manufacturers. The U.S. Inventory describes the methodology as follows:

"Emissions have been estimated using two sets of data. For 1990 through 1994, emissions were estimated based on the historical consumption of silicon (square centimeters), the estimated average number of interconnecting layers in the chips produced, and an estimated per-layer emission factor. (The number of layers per chip, and hence the PFC emissions per square centimeter of silicon, increases as the line-width of the chip decreases.) The average number of layers per chip was based on industry estimates of silicon consumption by line-width and of the number of layers per line-width. The per-layer emission factor was based on the total annual emissions reported by the participants in the PFC Emission Reduction Partnership for the Semiconductor Industry. For the three years for which gas sales data are available (1992 to 1994), the estimates derived using this method are within 10 percent of the estimates derived using gas sales data and average values for emission factors and (GWPs)."

"For 1995 through 1999, emissions were estimated based on the total annual emissions reported by the participants in the PFC Emission Reduction Partnership for the Semiconductor Industry. Partners estimate their emissions using a range of methods. The partners with relatively high emissions typically multiply estimates of their PFC consumption by process-specific emission factors that they have either measured or obtained from tool suppliers. To estimate total U.S. emissions from semiconductor manufacturing, based on reported partner emissions, a per-plant emission factor was estimated for the partners. This per-plant emission factor was then applied to PFC-using plants operated by semiconductor manufacturers who were not partners, considering the varying characteristics of the plants operated by partners and non-partners (e.g., typical plant size and employed linewidth technology). The resulting estimate of non-partner emissions was added to the emissions reported by the partners to obtain total U.S. emissions." (EPA 2001)

Data Sources

Three primary data sources were used to develop estimates of fluorinated greenhouse gas emissions from semiconductor manufacturing. National emission estimates (see Table 3-15) were obtained from the U.S. Inventory (EPA 2001). National and state population estimates (see Table 3-16) were obtained from the U.S Census Bureau (2000) and the California State Department of Finance (2001), respectively.

Table 3-15: National Fluorinated Greenhouse Gas Emissions from Semiconductor Manufacturing (MMTCO$_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Semiconductor Manufacturing	2.90	2.90	2.90	3.70	4.22	5.50	7.00	7.00	6.80	6.80

Source: EPA 2001

Table 3-16: Ratio of California to U.S. Population

Year	CA Population	U.S. Population	Ratio
1990	30,595,770	249,464,396	0.12
1991	30,945,000	252,153,092	0.12
1992	31,478,000	255,029,699	0.12
1993	31,858,000	257,782,608	0.12
1994	32,075,000	260,327,021	0.12
1995	32,223,000	262,803,276	0.12
1996	32,396,000	265,228,572	0.12
1997	32,743,000	267,783,607	0.12
1998	33,186,000	270,248,003	0.12
1999	33,660,000	272,690,813	0.12
2000	34,207,000	281,421,906	0.12

Electric Utilities

Sulfur hexafluoride (SF_6) gas is mostly used as an electrical insulator in circuit breakers, gas-insulated substations and switchgear. This equipment is used in the transmission and distribution of electricity (EPA 2001). The advantages of SF_6 include reduced flammability as well as allowing for more compact substations in dense urban areas (EPA 2001).

Sulfur hexafluoride emissions occur due to leaks and faulty seals, particularly in older equipment. Other emissions occur during installation and servicing. Venting does not occur much these days, due to increased awareness and increased costs of SF_6.

As shown in Table 3-17, emissions of SF_6 have increased by 17 percent between 1990 and 1999, from 1.60 to1.87 MMTCO$_2$ Eq. This trend is also reflected in total electricity consumption in California, which was at its highest in 1999. These emissions were 0.44 percent of gross emissions in California and 7 percent of national emissions from this source.

Table 3-17: SF$_6$ Emissions from Electric Utilities (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SF$_6$	1.60	1.63	1.74	1.74	1.80	1.81	1.81	1.87	1.80	1.87

Methodology

Since state-level SF_6 data are not available, state guidance provided in the EIIP guidance recommends that SF_6 emissions be estimated using the following equation (EIIP 1999):

$$State~SF_6~Emissions~=~National~SF_6~Emissions \times State~Electricity~Consumption$$
$$\div~National~Electricity~Consumption$$

This method treats electricity consumption data as a proxy for estimating fugitive SF_6 emissions occurring at equipment used in electricity transmission and distribution. The ratio of state electricity to national electricity consumption was used to pro-rate national emissions. State SF_6 emissions were calculated as the product of its relative share of national electricity consumption and national emissions.

Data Sources

National SF_6 emissions estimates (see Table 3-18) were obtained from the U.S. Inventory (EPA 2001). National and state electricity consumption data were obtained from the Energy Information Administration's *Annual Energy Review 2000* (EIA 2001).

Table 3-18: National SF$_6$ Emission Estimates from Electric Utilities (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SF$_6$	20.50	21.54	22.58	23.62	24.66	25.70	25.70	25.70	25.70	25.70

Source: EPA 2001

References

References for Cement

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IPCC (2000), *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, IPCC-XVI/Doc. 10 (1.IV.2000), May 2000.

USGS (1990-2000), *Minerals Yearbook: Cement*, U.S. Geological Survey, Reston, VA.

References for Lime Production

CDC (2001), Personal communication with Susan Kohler at the California Department of Conservation, Division of Mines and Geology.

EIIP (1999), *EIIP Volume VIII, Estimating Greenhouse Gas Emissions*, Emission Inventory Improvement Program, Technical Report Series, October 1999.

IPCC (2000), *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, IPCC-XVI/Doc. 10 (1.IV.2000), May 2000.

References for Limestone and Dolomite Consumption

EPA (2001), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999,* U.S. Environmental Protection Agency, Washington, DC, EPA 236-R-01-001, April 2001.

USGS (1994-2000), *Minerals Yearbook: Crushed Stone Annual Report*, U.S. Geological Survey, Reston, VA.

References for Soda Ash Production and Consumption

EIIP (1999), *EIIP Volume VIII, Estimating Greenhouse Gas Emissions*, Emission Inventory Improvement Program, Technical Report Series, October 1999.

U.S. CB (1996), *Annual Survey of Manufacturers*, 1996, U.S. Census Bureau, http://tier2.census.gov/asm/asm.htm.

USGS (1994-2001), *Mineral Yearbooks: Soda Ash Annual Report*, U.S. Geological Surveys, Reston, VA.

References for Carbon Dioxide Consumption

EPA (2001), Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999, U.S. Environmental Protection Agency, Washington, DC, EPA 236-R-01-001, April 2001.

SRI (1990, 1992, 1993, 1995, 1996, 1998), Directory of Chemical Producers, USA, SRI International, Menlo Park, CA.

References for Nitric Acid Production

EIIP (1999), *EIIP Volume VIII, Estimating Greenhouse Gas Emissions*, Emission Inventory Improvement Program, Technical Report Series, October 1999.

EPA (2001), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999,* U.S. Environmental Protection Agency, Washington, DC, EPA 236-R-01-001, April 2001.

IPCC (2000), *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, IPCC-XVI/Doc. 10 (1.IV.2000), May 2000.

SRI (1990, 1992, 1993, 1995, 1996, 1998), *Directory of Chemical Producers, USA*, SRI International, Menlo Park, CA.

References for ODS Substitutes

California State Department of Finance (2001) Historical Adjusted City, County and State Population Estimates, 1991-2000, with Adjusted 1990 Census Counts, California State Department of Finance, Demographic Research Unit, September 2001.

EPA (2001) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999. United States Environmental Protection Agency. Office of Atmospheric Programs. EPA 236-R-01-001. April 2001.

U.S. Census Bureau (2000) U.S. Bureau of the Census Internet Release date April 11, 2000; revised May 26, 2000.
<http://www.census.gov/population/estimates/nation/popclockest.txt>.

References for Semiconductor Manufacture

California State Department of Finance (2001) *Historical Adjusted City, County and State Population Estimates, 1991-2000*, with Adjusted 1990 Census Counts, California State Department of Finance, Demographic Research Unit, September 2001.

EPA (2001) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*. United States Environmental Protection Agency, Office of Atmospheric Programs, EPA 236-R-01-001, April 2001.

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References for Electric Utilities

EIA (2001), *Annual Energy Review 2000*, Energy Information Administration, U.S. Department of Energy, DOE/EIA-0384(00), August 2001.

EIIP (1999), *EIIP Volume VIII, Estimating Greenhouse Gas Emissions*, Emission Inventory Improvement Program, Technical Report Series, October 1999.

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Chapter 4

Agriculture

Methane (CH_4) and nitrous oxide (N_2O) are emitted from a variety of agricultural sources, including enteric fermentation, manure management, rice cultivation, agricultural soil management, and agricultural residue burning.

California agriculture generated 12.9 million metric tons of carbon dioxide equivalent emissions ($MMTCO_2$ Eq.) of CH_4 and 15.6 $MMTCO_2$ Eq. of N_2O, for a total of approximately 28.4 $MMTCO_2$ Eq. of greenhouse gas emissions in 1999 (see Table 4-1). Emissions from agriculture represented nearly 7 percent of 1999 gross emissions in California. In 1999, California's agricultural emissions represented approximately 6 percent of national emissions from agricultural sources.

Agricultural soil management is the primary source of agricultural N_2O emissions, yielding 95 percent of emissions in 1999. Methane emissions from agriculture are driven by enteric fermentation and manure management, representing 55 and 41 percent of 1999 emissions, respectively.

Table 4-1: Emissions from Agriculture (MMTCO$_2$ Eq.)

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH$_4$	**11.26**	**11.51**	**11.74**	**11.11**	**11.98**	**12.33**	**11.87**	**12.34**	**12.17**	**12.85**
Enteric Fermentation	7.53	7.25	7.37	6.59	7.14	7.25	6.77	6.88	6.84	7.08
Manure Management	3.29	3.87	3.93	4.03	4.30	4.55	4.55	4.88	4.80	5.21
Rice Cultivation	0.41	0.36	0.41	0.45	0.50	0.48	0.52	0.54	0.50	0.52
Agricultural Residue Burning	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
N$_2$O	**15.82**	**14.19**	**14.50**	**15.51**	**14.86**	**16.76**	**16.32**	**14.92**	**15.26**	**15.57**
Agricultural Soils	14.93	13.35	13.68	14.69	14.04	15.93	15.51	14.10	14.45	14.74
Manure Management	0.81	0.76	0.74	0.72	0.70	0.72	0.70	0.70	0.70	0.71
Agricultural Residue Burning	0.09	0.08	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.12
Total	**27.09**	**25.70**	**26.24**	**26.62**	**26.84**	**29.09**	**28.20**	**27.25**	**27.43**	**28.42**

Note: Totals may not sum due to independent rounding.

Enteric Fermentation

Methane is produced in the digestive system of animals, as microbes ferment food consumed by the animal. This process, known as enteric fermentation, results in the production and eventual release of CH_4 through exhalation or eructation. The quantity of CH_4 produced is dependent on the type of digestive system and the diet characteristics of the animal.

Animals can have either a ruminant or non-ruminant digestive system. Ruminants, such as cattle, sheep, goats, camels, and buffalo, emit the majority of CH_4 because fermentation occurs in their rumen, or "fore-stomach." The fore stomach allows coarse plant material to be digested through microbial fermentation, so that the animal can utilize the products. Non-ruminant animals, such as pigs, horses, mules, rabbits, and guinea pigs produce CH_4 through microbial fermentation in the large intestine. Fermentation in the large intestine produces less CH_4 than fermentation in the fore stomach; thus, these animals produce less CH_4 (on a per-animal basis) than ruminant animals.

Methane emission estimates from enteric fermentation are shown in Table 4-2. Total emissions from livestock in California in 1999 were 7.08 MMTCO$_2$ Eq.

Table 4-2: CH$_4$ Emissions from Enteric Fermentation in California (10^3 MTCO$_2$ Eq.)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cattle	3,669	3,742	3,861	3,548	3,824	3,878	3,556	3,752	3,776	4,052
Beef Cattle	3,444	3,089	3,089	2,637	2,885	2,951	2,800	2,724	2,673	2,630
Horses	240	241	242	243	242	243	244	244	245	248
Sheep	168	171	167	150	181	171	155	148	134	136
Swine	6	7	8	8	8	8	7	7	7	6
Goats	4	4	4	4	4	4	4	4	4	4
Total	**7,531**	**7,253**	**7,371**	**6,590**	**7,144**	**7,255**	**6,765**	**6,879**	**6,839**	**7,076**

Note: Totals may not sum due to independent rounding.

On average, CH$_4$ produced through the process of enteric fermentation accounted less than 2 percent of gross California emissions, with emissions of 7.53 MMTCO$_2$ Eq. in 1990 and 7.08 MMTCO$_2$ Eq. in 1999. Overall, emissions from this source decreased by 6 percent between 1990 and 1999, with maximum emissions occurring in 1990, and a great deal of fluctuation in the following years. The main driver for this decrease is the declining beef cattle population in California during this timeframe. Emissions from this source in California represent roughly 6 percent of U.S. emissions from enteric fermentation. In the United States, CH$_4$ emissions from enteric fermentation account for approximately 2 percent of gross emissions and have decreased 2 percent since 1990. The national decrease in emissions is driven by a decrease in both dairy cattle populations and emission factors.

Because emissions by animal type are estimated based on animal populations and animal-specific emission factors, animals with the greatest populations and highest emission factors are likely to account for the majority of emissions. Thus, the majority of emissions from enteric fermentation – both in California and in the United States – are attributable to beef and dairy cattle.

Methodology

Due to their large population, large size, and particular digestive characteristics, cattle account for the majority of CH$_4$ emissions from livestock in California. Additionally, cattle production systems are better characterized in comparison with other livestock management systems. As a result, a more detailed methodology, i.e., Intergovernmental Panel on Climate Change (IPCC) Tier 2, was used for estimating emissions for cattle. While emission estimates for sheep, goats, swine, and horses were handled using the simpler IPCC Tier 1 approach.

The methodology for estimating emissions from enteric fermentation is based on the methodology utilized in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001), where it is described using the four steps below.

Step 1: Characterize the Cattle Population

"Each stage in the cattle life cycle was modeled to simulate the cattle population from birth to slaughter. This level of detail accounts for the variability in methane emissions associated with each life stage. Given cattle often remain in one stage for less than one year (e.g., beef calves are weaned at 7 months), the stages are modeled on a per month basis. The type of cattle use also impacts

methane emissions (e.g., beef versus dairy). Consequently, cattle life stages were modeled for several categories of dairy and beef cattle." (EPA 2001)

The categories used to estimate population include:

- calves;
- dairy cows;
- dairy heifer replacements;
- beef cows;
- beef heifer replacements;
- heifer and steer stockers;
- feedlot animals; and
- bulls.

The statistics gathered for each category include birth estimates, end of year population data, feedlot placement information, and slaughter weight data. These statistics were used in the model to initiate and track cohorts of individual animal types having distinct emissions profiles. Other performance factors, such as pregnancy, lactation, average weights, and weight gain, are also tracked for each of the cattle population categories.

The average annual population for each cattle category is shown in Table 4-3. Note that these populations differ from those reported by the California Agricultural Statistics Service (CASS) to the U.S. Department of Agriculture (USDA) because the model calculates monthly population variations. As a result, the cattle population modeled for estimates of emissions from enteric fermentation will not correspond to the cattle population used to estimate emissions from manure management, which is taken from the USDA estimates. Calf populations are not given, because cattle do not emit CH_4 until they are weaned. Populations of cattle from age 0-6 months are used only to track populations as they get older and begin to emit CH_4.

Table 4-3: Average Annual Cattle Populations by Sub-Category (1,000 Head)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cows	1,115	1,150	1,160	1,200	1,233	1,271	1,320	1,379	1,399	1,440
Dairy Replacements (7-12 Months)	153	150	166	165	182	186	191	192	201	210
Dairy Replacements (12-23 Months)	367	355	390	392	430	444	457	462	470	504
Beef Cows	955	900	880	840	861	849	838	816	815	810
Beef Replacements (7-12 Months)	37	37	36	34	37	36	35	34	33	33
Beef Replacements (12-23 Months)	87	87	82	78	88	88	85	84	81	78
Steer Stockers	423	329	374	391	391	385	377	368	344	284
Heifer Stockers	0	36	63	31	32	20	46	27	13	13
Feedlot Animals	446	346	332	159	311	366	307	328	339	378
Bulls[a]	71	70	69	69	75	75	70	69	64	69

[a] Note that only the end-of-year census statistics were used for bulls.

Step 2: Characterize Cattle Nutrition

"To support development of digestible energy (DE, the percent of gross energy intake digestible to the animal) and methane conversion rate (Y_m, the fraction of gross energy converted to methane) values for each of the cattle population categories, data were collected on diets considered representative of different regions. For both grazing animals and animals being fed mixed rations, representative regional diets were estimated using information collected from state livestock specialists and from USDA (1996a). The data for each of the diets (e.g., proportions of different feed constituents, such as hay or grains) were used to determine chemical composition for use in estimating DE and Y_m for each animal type."

"DE and Y_m values were estimated for each cattle population category based on physiological modeling and expert opinion. DE and Y_m values for dairy cows and most grazing animals were estimated using a model (Donovan and Baldwin 1999) that represents physiological processes in the ruminant animals. The three major categories of input required by the model are animal description (e.g., cattle type, mature weight), animal performance (e.g., initial and final weight, age at start of period), and feed characteristics (e.g., chemical composition, habitat, grain or forage). Data used to simulate ruminant digestion is provided for a particular animal that is then used to represent a group of animals with similar characteristics. The model accounts for differing diets (i.e., grain-based, forage-based, range-based), so that Y_m values for the variable feeding characteristics within the U.S. cattle population can be estimated."

"For feedlot animals, DE and Y_m values were taken from Johnson (1999). In response to peer reviewer comments (Johnson 2000), values for dairy replacement heifers are based on EPA (1993)." (EPA 2001)

These diet characteristics are used to implement the equations described for Tier 2 in the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). The average annual emission factors implied by the models calculations are shown in Table 4-4.

Table 4-4: Implied Emission Factors for Cattle, by Sub-Category (kg CH_4/head/yr)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cows	130	130	131	115	120	117	101	103	101	106
Dairy Replacements (7-12 Months)	40	40	40	40	40	40	40	40	40	40
Dairy Replacements (12-23 Months)	63	63	63	63	63	63	63	63	63	63
Beef Cows	83	83	83	83	83	83	83	83	83	83
Beef Replacements (7-12 Months)	47	47	47	47	47	47	47	47	47	47
Beef Replacements (12-23 Months)	74	74	74	74	74	74	74	74	74	74
Steer Stockers	64	64	64	64	64	64	64	64	64	64
Heifer Stockers	NA	56	57	57	57	57	57	57	57	57
Feedlot Animals	47	49	47	46	37	38	35	33	33	33
Bulls[a]	100	100	100	100	100	100	100	100	100	100

[a]Note that the national emission factor was used for bulls.

Step 3: Determine Cattle Emissions

"In order to estimate methane emissions from cattle, the population was divided into region, age, sub-type (e.g., calves, heifer replacements, cows, etc.), and production (i.e., pregnant, lactating, etc.) groupings to more fully capture any differences in methane emissions from these animal types. Cattle diet characteristics developed under Step 2 were used to develop regional emission factors for each sub-category. Tier 2 equations from IPCC (2000) were used to produce methane emission factors for the following cattle types: dairy cows, beef cows, dairy replacements, beef replacements, steer stockers, heifer stockers, steer feedlot animals, heifer feedlot animals, and steer and heifer feedlot step-up diet animals. To estimate emissions from cattle, population data were multiplied by the emission factor for each cattle type." (EPA 2001)

Emissions for each cattle sub-category are shown in Table 4-5.

Table 4-5: CH$_4$ Emissions from Enteric Fermentation from Cattle, by Sub-Category (Gg)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cows	145	150	153	137	148	149	133	142	142	153
Dairy Replacements (7-12 Months)	6	6	7	7	7	8	8	8	8	8
Dairy Replacements (12-23 Months)	23	22	25	25	27	28	29	29	30	32
Beef Cows	80	75	73	70	72	71	70	68	68	68
Beef Replacements (7-12 Months)	2	2	2	2	2	2	2	2	2	2
Beef Replacements (12-23 Months)	6	6	6	6	6	6	6	6	6	6
Steer Stockers	27	21	24	25	25	25	24	24	22	18
Heifer Stockers	0	2	4	2	2	1	3	2	1	1
Feedlot Animals	21	17	16	7	12	14	11	11	11	12
Bulls	7	7	7	7	7	8	7	7	6	7

Step 4: Determine Other Livestock Emissions

Emission estimates for other animal types, including sheep, goats, swine, and horses, were based upon average emission factors representative of entire populations of each animal type. Methane emissions from these animals accounted for a minor portion of total CH$_4$ emissions from livestock in California from 1990 through 1999. Populations and emission factors used in calculating emissions from other livestock are shown in Table 4-6 and Table 4-7, respectively.

Table 4-6: Populations for Other Domesticated Livestock (1,000 Head)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Horses	635	638	641	642	640	642	644	644	647	655
Sheep	1,000	1,015	995	895	1,080	1,020	920	880	800	810
Swine	195	215	265	260	255	240	210	210	210	190
Goats	34	34	34	35	36	38	39	40	40	40

Source: AHC 1996; FAO 2001; USDA 1994a-b; 1998b; 1999d,g,e; 2000b,d

Table 4-7: Emission Factors for Other Domesticated Livestock (kg CH_4/head/year)

Livestock Type	Emission Factor
Horses	18
Sheep	8
Swine	1.5
Goats	5

Source: IPCC 2000

Data Sources

Data for non-equine animal populations was state level data compiled from data collected by the California Agricultural Statistics Service (CASS) (Coe 2001) and published in reports issued by the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA 1994a-b, 1995a-b, 1996, 1997, 1998a-b, 1999a-g, 2000a-e). Since equine data was not available at the state-level, the equine population was estimated using California data for 1995 from the American Horse Council (AHC 1996) in conjunction with national population statistics available from the Food and Agriculture Organization (FAO 2001). Horses were assumed to constitute the entire equine population, since their numbers overwhelm any of the other equine animal types. Diet characterizations and the associated emission factors for cattle were taken from the model used in the U.S. Inventory (EPA 2001). Most of these emission factors were available at the regional level; however, there is an emission factor specifically for California because it is treated as its own region. Emission factors for bulls and other livestock were obtained from the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), and are consistent with the U.S. Inventory.

Manure Management

Methane and N_2O are both produced during the management of livestock manure. Methane is produced when manure decomposes anaerobically. Nitrous oxide is produced from the nitrogen in manure and urine as it goes through the nitrogen cycle and the processes of nitrification and denitrification.

If manure is managed in a liquid storage system (e.g., lagoons, ponds, tanks, or pits) anaerobic conditions occur and CH_4 is produced as a result. If manure is managed as a solid or deposited on pastures or rangelands, the aerobic conditions produce little or no CH_4 during decomposition. Other factors that contribute to the amount of CH_4 produced are temperature, moisture levels, and manure composition. Generally as temperature and moisture increase, so does the amount of CH_4 produced. Manure composition is dependent on diet type, with diets consisting of higher energy content and digestibility producing greater quantities of CH_4.

Nitrous oxide emissions from livestock manure and urine occur when the waste first goes through a period of aerobic decomposition, followed by a period of anaerobic decomposition. This process allows nitrification (conversion of ammonia nitrogen to nitrites) to occur during the aerobic phase and denitrification (conversion of nitrites to N_2O) to occur during the anaerobic stage. Emissions of N_2O are likely to occur in management systems that will provide these conditions. For example, in a drylot system the conditions are generally aerobic, allowing nitrification to occur. However, anaerobic pockets may develop after periods of rain, enabling the waste to undergo denitrification and thus produce N_2O emissions.

Some of these N_2O emissions from livestock manure and urine are accounted for under agricultural soil management. These include manure and urine on pastures, ranges, or paddocks, as well as manure that is spread directly on fields or as daily spread after removal from a management system (e.g., lagoon, pit, etc.). All other N_2O emissions associated with manure management are estimated in this section.

Methane emission estimates from manure management are shown in Table 4-8. Methane emissions from livestock in California in 1999 were 5.21 MMTCO$_2$ Eq. Total N_2O emissions in California in 1999 were 0.71 MMTCO$_2$ Eq., as shown in Table 4-9. Total emissions from manure management in California were 5.92 MMTCO$_2$ Eq., as shown in Table 4-10.

Table 4-8: CH$_4$ Emissions from Manure Management (10^3 MTCO$_2$ Eq.)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	99	92	88	90	88	90	85	86	86	89
Dairy Cattle	2,920	3,492	3,543	3,652	3,919	4,170	4,183	4,508	4,431	4,834
Swine	64	72	90	88	86	87	75	76	68	65
Poultry	136	137	133	126	130	133	133	139	138	146
Other	72	74	75	76	76	75	74	74	73	74
Sheep	12	15	15	16	16	15	14	13	12	12
Goats	2	2	2	2	2	2	2	2	2	2
Horses	57	58	58	58	58	58	58	58	59	59
Total	3,291	3,869	3,930	4,032	4,299	4,555	4,550	4,882	4,796	5,208

Note: Totals may not sum due to independent rounding.

Table 4-9: N$_2$O Emissions from Manure Management (10^3 MTCO$_2$ Eq.)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	166	142	128	148	121	136	110	123	130	134
Dairy Cattle	261	257	276	277	297	304	309	314	321	342
Swine	0	0	0	0	0	0	0	0	0	0
Poultry	369	349	320	279	270	270	265	253	237	225
Other	10	12	12	13	13	12	12	11	11	11
Sheep	7	9	9	10	10	9	8	8	7	7
Goats	3	3	3	3	3	3	3	3	3	3
Horses	-	-	-	-	-	-	-	-	-	-
Total	806	759	736	716	702	724	696	702	699	712

Note: Totals may not sum due to independent rounding.

Table 4-10: Total Emissions from Manure Management (10³ MTCO₂ Eq.)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	264	234	216	238	210	227	196	209	216	223
Dairy Cattle	3,181	3,749	3,819	3,929	4,216	4,474	4,492	4,822	4,752	5,176
Swine	64	73	90	88	86	87	75	76	68	65
Poultry	505	486	454	405	400	403	398	392	375	371
Other	82	86	87	88	89	88	86	85	83	84
Sheep	20	24	24	25	26	24	22	21	19	19
Goats	5	5	5	5	5	5	5	5	5	5
Horses	57	58	58	58	58	58	58	58	59	59
Total	4,096	4,628	4,666	4,748	5,001	5,279	5,246	5,584	5,494	5,919

Note: Totals may not sum due to independent rounding.

In California, manure management resulted in 1.4 percent of gross state emissions in 1999. Methane accounted for the majority of emissions with 88 percent, while N_2O emissions represent 12 percent of total emissions from this source in 1999. Over the period from 1990 through 1999, emissions from manure management increased by more than 44 percent, due almost entirely to the increase in CH_4 emissions from dairy cows. Dairy cow CH_4 emissions increased 65 percent as a result of increases in population, VS production, and the weighted MCF.

U.S. emissions from manure management followed a similar trend during this period. Total emissions from manure management in the United States rose from 42.4 MMTCO₂ Eq. in 1990 to 51.6 MMTCO₂ Eq. in 1999, a 22 percent increase (EPA 2001). This trend in U.S. emissions was driven by increased emissions from both swine and dairy cows.

Dairy cattle accounted for the majority of CH_4 emissions from manure management, followed by poultry, beef cattle, swine, horses, sheep and goats. In the United States, swine are responsible for the greatest CH_4 emissions from manure management, followed by dairy cattle, beef cattle, and poultry. Methane emissions from manure management in California represented 15 percent of 1999 U.S. emissions from this source.

As shown in Table 4-9, the majority of N_2O emissions from manure management in California were from poultry and dairy cattle, followed beef cattle, with minor emissions from sheep and goats. Similarly in the United States, poultry are the greatest source of N_2O emissions, followed by beef and dairy cattle. Nitrous oxide emissions from manure management in California represented 2 percent of 1999 U.S. emissions from this source.

Methodology

Methane and N_2O emissions from manure management systems are estimated using the methods outlined in *EIIP Volume VIII: Estimating Greenhouse Gas Emissions* (EIIP 1999) and the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). Both types of emissions are functions of livestock populations, animal-specific emissions factors, and manure management practices, and emissions factors for manure management. Tables 4-11 through 4-16 present the livestock populations, animal-specific data, methane conversion factors (MCFs), N_2O emission factors, and manure management system data used for this analysis. The steps for calculating the CH_4 and N_2O emissions are outlined below.

Methane Emissions

The main driver of CH_4 emissions from this source is the quantity of volatile solids produced by livestock. Volatile solids are defined as the solid organic fraction of manure that will oxidize and be driven off as a gas at a temperature of 1,112 degrees Fahrenheit. To estimate the amount of volatile solids, livestock population is multiplied by a typical animal mass (TAM) factor and the ratio of volatile solids to TAM. The potential CH_4 emissions are then calculated by multiplying the volatile solids by an animal-specific CH_4 generating capacity factor. Finally, potential CH_4 emissions were multiplied by a weighted MCF that accounts for the percent of the population in each management system and the effect that each particular management system has on CH_4 emissions. The MCF is always between zero and one, with zero representing a zero emissions management practice and one representing a practice that maximizes CH_4 emissions.

Nitrous Oxide Emissions

The main driver of N_2O emissions is the amount of unvolatilized nitrogen in manure, either organically bound or in the form of ammonia. This quantity of nitrogen is termed the total Kjeldahl nitrogen. Kjeldahl nitrogen is estimated as the product of animal population, TAM, and the ratio of TAM to Kjeldahl nitrogen. Eighty percent of the total Kjeldahl nitrogen was considered to remain unvolatilized. To calculate emissions, the unvolatilized nitrogen was multiplied by an emission factor, weighted by the management systems used, which expresses how much of the nitrogen is emitted as N_2O. It is important to note that this method only calculates emissions for managed systems; N_2O emissions from manure applied to agricultural soils via daily spread operations or deposition onto pasture, range, or paddock are accounted for under the agricultural soils method.

Table 4-11: Annual Livestock Populations by Sub-Category (1,000 Head)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef										
Feedlot Steers	371	305	275	321	272	305	242	275	289	293
Feedlot Heifers	90	90	82	90	67	75	65	68	72	81
NOF Bulls	71	70	69	69	75	75	70	69	64	69
NOF Calves	1,227	1,337	1,210	1,243	1,348	1,331	1,335	1,339	1,365	1,465
NOF Heifers	235	236	241	222	238	229	240	226	212	225
NOF Steers	344	288	324	308	361	334	367	345	307	323
NOF Cows	962	912	892	859	872	861	845	824	826	815
Dairy										
Dairy Cows	1,114	1,140	1,158	1,203	1,230	1,271	1,319	1,379	1,400	1,441
Dairy Heifers	521	505	553	548	601	613	619	623	638	687
Swine										
Breeding Swine	28	29	37	33	32	31	27	27	27	25
Market Swine	167	186	228	227	223	209	183	183	183	165
Market<60lb.	60	64	82	74	70	65	57	60	70	55
Market 60-119 lb.	49	51	58	60	65	58	51	45	50	50
Market 120-179 lb.	31	40	45	49	45	44	40	45	40	35
Market >180 lb.	27	31	43	44	43	42	35	33	23	25
Poultry										
Layers	35,900	35,200	33,300	31,300	31,500	29,700	29,800	30,500	29,993	31,248
Hens > 1 yr	18,000	17,200	17,700	16,500	17,200	16,860	16,520	15,270	14,350	13,568
Pullets	17,690	17,900	15,500	14,700	14,218	12,750	13,230	15,090	15,558	17,600
Chickens	210	100	100	100	82	90	50	140	85	80
Broilers	42,018	43,673	42,364	39,273	41,127	42,873	42,582	43,145	43,145	43,145
Turkeys	13,125	11,757	10,500	8,654	7,875	8,049	8,036	7,326	6,477	5,833
Other										
Sheep	1,000	1,015	995	895	1,080	1,020	920	880	800	810
Feedlot	225	280	285	305	305	288	259	248	226	228
Not on Feed	775	735	710	590	775	732	661	632	574	582
Goats	34	34	34	35	36	38	39	40	40	40
Horses	635	638	641	642	640	642	644	644	647	655

Source: AHC 1996, FAO 2001, USDA 1994a-6, 1995a-b, 1998a-b, 1999a-d, 2000a-g

Table 4-12: Constants for Calculating Emissions

Livestock Type	Average TAM (kg)	Total Kjeldahl Nitrogen (kg/day/ 1000 kg mass)	Volatile Solids (VS) (kg/day/1000 kg mass)	Maximum CH$_4$ Generation Potential (m^3 CH$_4$/kg VS)
Feedlot Steers	420	0.3	5.44	0.33
Feedlot Heifers	420	0.3	5.44	0.33
NOF Bulls	750	0.31	6.04	0.17
NOF Calves	159	0.3	6.41	0.17
NOF Heifers	590	0.33	6.20	0.17
NOF Steers	318	0.31	6.04	0.17
NOF Cows	420	0.31	6.04	0.17
Dairy Cows	604	0.44	See Table 4-6	0.24
Dairy Heifers	476	0.31	7.77	0.17
Breeding Swine	198	0.24	2.6	0.48
Market Swine <60 lb.	15.9	0.60	8.8	0.48
Market Swine 60-119 lb.	40.6	0.42	5.40	0.48
Market Swine 120-179 lb.	67.8	0.42	5.40	0.48
Market Swine >180 lb.	90.8	0.42	5.40	0.48
Hens > 1 yr	1.8	0.83	10.8	0.39
Pullets	1.8	0.62	9.7	0.39
Chickens	1.8	0.83	10.8	0.39
Broilers	0.9	1.10	15.00	0.36
Turkeys	6.8	0.74	9.70	0.36
Sheep on Feed	27	0.42	9.21	0.36
Sheep not on Feed	27	0.42	9.21	0.19
Goats	64	0.45	9.53	0.17
Horses	450	0.30	10.00	0.33

Source: EIIP 1999, EPA 2001

Table 4-13: Volatile Solids Produced Per Cow Based on Milk Production (kg/day/1000 kg mass)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cows	8.50	8.52	8.57	8.61	8.96	8.80	8.69	8.87	8.77	9.11

Source: EPA 2001

Table 4-14: Weighted MCFs by Animal Type (percent)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef										
Feedlot Steers	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%
Feedlot Heifers	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.8%	1.9%
NOF Bulls	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
NOF Calves	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
NOF Heifers	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
NOF Steers	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
NOF Cows	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Dairy										
Dairy Cows	41.5%	48.4%	48.1%	47.5%	47.9%	50.2%	49.2%	49.7%	48.6%	49.7%
Dairy Heifers	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%
Swine										
Breeding Swine	45.2%	45.9%	45.9%	45.1%	45.4%	47.7%	47.2%	47.7%	46.1%	47.2%
Market Swine										
Market<60lb.	45.0%	45.8%	45.7%	45.0%	45.3%	47.8%	47.3%	47.9%	46.3%	47.4%
Market 60-119 lb.	45.0%	45.8%	45.7%	45.0%	45.3%	47.8%	47.3%	47.9%	46.3%	47.4%
Market 120-179 lb.	45.0%	45.8%	45.7%	45.0%	45.3%	47.8%	47.3%	47.9%	46.3%	47.4%
Market >180 lb.	45.0%	45.8%	45.7%	45.0%	45.3%	47.8%	47.3%	47.9%	46.3%	47.4%
Poultry										
Layers										
Hens > 1 yr	7.4%	7.8%	8.1%	8.3%	8.7%	9.4%	9.4%	9.8%	10.1%	10.6%
Pullets	7.4%	7.8%	8.1%	8.3%	8.7%	9.4%	9.4%	9.8%	10.1%	10.6%
Chickens	7.4%	7.8%	8.1%	8.3%	8.7%	9.4%	9.4%	9.8%	10.1%	10.6%
Broilers	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Turkeys	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Other										
Sheep										
Feedlot	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Not on Feed	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Goats	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Horses	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%

Source: EIIP 1999, EPA 2000

Table 4-15: Weighted N$_2$O Emission Factors for Managed Systems (kg N$_2$O/kg N excreted)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef										
Feedlot	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200
Not on Feed	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dairy										
Dairy Cows	0.0020	0.0020	0.0020	0.0020	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019
Dairy Heifers	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200
Swine	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017
Poultry										
Layers	0.0114	0.0106	0.0098	0.0091	0.0083	0.0076	0.0068	0.0060	0.0053	0.0045
Broilers & Turkeys	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sheep										
Feedlot	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Not on Feed	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Goats	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Horses	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Source: EIIP 1999, EPA 2000

Table 4-16: Percent of Manure Managed by Animal Type (percent)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef										
Feedlot	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Not on Feed	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dairy										
Dairy Cows	86%	86%	86%	87%	87%	87%	88%	88%	88%	88%
Dairy Heifers	86%	86%	86%	87%	87%	87%	88%	88%	88%	88%
Swine	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Poultry										
Layers & Broilers	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Turkeys	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%
Sheep										
Feedlot	100%	100%	99%	99%	100%	100%	100%	100%	100%	100%
Not on Feed	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%
Goats	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Horses	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Source: EIIP 1999, EPA 2000

Data Sources

Data for non-equine animal populations was state-level data compiled from data collected by the California Agricultural Statistics Service (CASS) (Coe 2001) and published in reports issued by the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA 1994a-b, 1995a-b, 1998a-b, 1999a-d, 2000a-g). Since equine data was not available at the state level, the equine population was estimated using California data for 1995 from the American Horse Council (AHC 1996) in conjunction with national population statistics available from the Food and Agriculture Organization (FAO 2001). Horses were assumed to constitute the entire equine population, since their numbers overwhelm any of the other equine animal types.

Where possible, state-level data was taken from the analysis used for the U.S. Inventory (EPA 2001). Data gleaned from this source includes:

- typical animal mass (TAM) for each livestock type;

- Kjeldahl nitrogen for each livestock type;

- volatile solid production for each livestock type, except sheep, goats, and horses;

- methane generating capacity for each livestock type, except sheep, goats, and horses;

- weighted MCFs for each livestock type, except NOF beef, sheep, goats, and horses;

- weighted N_2O emissions factors for all livestock types, except sheep and goats; and

- percent of manure in managed systems for all livestock, except poultry, goats, and horses.

When data was not available from the U.S. Inventory, California data from the EIIP guidance was used (EPA 2001, EIIP 1999). Data from EIIP, Chapter 7, includes:

- volatile solid production for sheep, goats, and horses;

- methane generating capacity for sheep, goats, and horses;

- weighted MCFs for NOF beef, sheep, goats, and horses;

- weighted N_2O emissions factors for sheep and goats; and

- percent of manure in managed systems for poultry, goats, and horses.

Rice Cultivation

All rice in California is grown on flooded fields. This cropping practice results in anaerobic conditions in the soil, and production of CH_4 by soil decomposing methanogenic bacteria. Most of this CH_4 produced by bacteria is either oxidized by methanotrophic soil bacteria or dissolved in ground water and leached away. However, some of the CH_4 is transferred from the soil to the atmosphere via diffusive transport through the rice plants.

Rice cultivation is a small source of CH_4 emissions in California. In 1999, CH_4 emissions from this source totaled approximately 0.52 MMTCO$_2$ Eq., less than 1 percent, of gross emissions in the state (see Table 4-17). From 1990-1999 emissions from rice cultivation fluctuated, but showed an increasing trend in response to the increase in rice area harvested. Emissions from rice cultivation in California grew by 27 percent over this ten-year period while national emissions increased by roughly 23 percent. Rice cultivation in California accounted for approximately 5 percent of national emissions from this source in 1999.

Table 4-17: CH_4 Emissions from Rice Cultivation (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH_4	0.41	0.36	0.41	0.45	0.50	0.48	0.52	0.54	0.50	0.52

Methodology

Methane emissions from rice cultivation are estimated using the method outlined in the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997). Though the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001) did not follow this method, the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000,* scheduled to be published in 2002, is expected to employ this methodology.

California emissions were estimated by multiplying the area of rice harvested annually in California by a California-specific seasonal emission factor:

CH_4 Emissions from Rice Cultivation = Harvested rice area (hectares) x CA-specific seasonal emission factor (kg CH_4/ha-season)

The California-specific seasonal emission factor is 122 kg CH_4/ha-season. This emission factor was derived from the scientific literature.

To enable quantitative comparisons between greenhouse gases, CH_4 emissions were converted into a standard unit, MMTCO$_2$ Eq. The units of CH_4 emitted were multiplied by the global warming potential (GWP) for CH_4 and then divided by 10^9 to convert from kilograms to million metric tons.

Data Sources

Data for the area of rice harvested, shown in Table 4-18, were obtained from the California Rice Commission (2000). This source drew on information presented in *California Field Crops Statistics 1983-92* (California Department of Food and Agriculture 1993), *Rice Situation & Outlook Report* (United States Department of Agriculture 1994), and *California Field Crop Review* (California Department of Food and Agriculture 2001).

Table 4-18: Rice Areas Harvested (1,000 Hectares)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Area	160	142	160	177	196	188	203	209	194	205

Source: California Rice Commission 2000

The California-specific seasonal emission factor was derived from published results of field measurements of CH_4 emissions from California rice fields (Cicerone et al. 1992, Bossio et al. 1999, Fitzgerald et al. 2000, and Redeker et al. 2000). Measured seasonal CH_4 emissions from all plots on which rice was grown were averaged to derive the emission factor of 122 kg CH_4/ha-season.[1] To represent the wide range of rice cultivation conditions that exist in California (and that vary from farm-to-farm as well as from year-to-year), experiments on fields with and without added nitrogen fertilizer, experiments on fields with and without winter flooding, and experiments with all variations of rice straw management (incorporated, rolled, or burned) were included.

Agricultural Soil Management

The microbial processes of nitrification and denitrification[2] naturally produce N_2O in soils. As a result of agricultural cropping practices designed to augment the amount of nitrogen in soils, the nitrogen available to microorganisms for nitrification and denitrification increases, subsequently increasing the amount of N_2O emitted from the soils. Nitrogen can be applied to or deposited on soils both directly and indirectly.

Soil management activities that add nitrogen to soils directly include fertilizer use; application of livestock manure during daily spread operations (i.e., manure and urine spread directly onto fields without going through a manure management system); application of sewage sludge and crop residues; and production of nitrogen-fixing crops. The cultivation of high-organic content soils (histosols) heightens the mineralization of existing nitrogen-rich organic matter that is naturally present in histosols, thereby increasing N_2O emissions from these soils (EPA 2001). Nitrous oxide emissions from soils are also enhanced by manure deposited directly on soils by animals in pastures, ranges, and paddocks.

Indirect emissions of N_2O induced by agricultural applications of nitrogen and livestock excretion occur through two pathways: (1) nitrogen volatilization to NH_3 and

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[1] Some rice fields in these experiments were left unvegetated as control plots.

[2] Nitrification is the anaerobic process by which bacteria oxidize ammonium salts to nitrites, and then further oxidize the nitrites to nitrates. Denitrification occurs when bacteria reduce nitrate to gaseous nitrogen compounds, resulting in the release of nitrogen to the atmosphere. Nitrous oxide is produced as a byproduct of both of these processes (Brock 1994).

NO$_x$, causing eventual atmospheric deposition and ultimately leading to emissions of N$_2$O from soils; and (2) leaching and runoff of fertilizer and animal waste nitrogen into groundwater and surface water systems. Indirect emissions of N$_2$O through atmospheric deposition can also occur from non-agricultural sources such as NO$_x$ emissions from transportation and power generation; however, indirect emissions from these sources are largely uncertain and are not estimated in this analysis.

Nitrous oxide emissions from agricultural soils accounted for 14.9 MMTCO$_2$ Eq. in 1990 and 14.7 MMTCO$_2$ Eq. in 1999, representing roughly 3 percent of gross emissions in California. Direct emissions from agricultural soils decreased by 3.5 percent, while indirect emissions remained relatively constant through the ten-year period. Nitrous oxide emissions from the sector as a whole decreased by just over one percent from 1990 through 1999, mainly as a result of a slight decline in fertilizer consumption. Among all emission sources in this sector, the only ones that increased from 1990 to 1999 were direct emissions from crop residues and indirect emissions from livestock manure.

As shown in Table 4-19, indirect emissions accounted for approximately 61 percent of total emissions, with direct emissions accounting for the remaining 39 percent. The greatest sources of indirect N$_2$O emissions from agricultural soils were livestock and leaching/runoff, which comprised 25 percent and 19 percent of total emissions from agricultural soils, respectively. Commercial fertilizer application was the dominant source of direct N$_2$O emissions, accounting for 18 percent of total emissions.

Table 4-19: N$_2$O Emissions from Agricultural Soils (MMTCO$_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Direct	**5.99**	**5.31**	**5.39**	**5.76**	**5.57**	**6.23**	**6.07**	**5.53**	**5.64**	**5.78**
Fertilizers	2.82	2.27	2.46	2.92	2.54	3.33	3.16	2.54	2.70	2.72
Crop Residues	0.37	0.32	0.35	0.37	0.40	0.38	0.41	0.45	0.43	0.43
N-Fixing Crops	1.32	1.28	1.15	1.07	1.18	1.09	1.08	1.15	1.14	1.23
Histosols	0.18	0.16	0.16	0.15	0.15	0.15	0.15	0.14	0.14	0.14
Livestock	1.31	1.29	1.27	1.24	1.30	1.28	1.27	1.25	1.24	1.26
Indirect	**8.94**	**8.03**	**8.28**	**8.93**	**8.48**	**9.69**	**9.45**	**8.57**	**8.80**	**8.96**
Fertilizers	2.50	2.02	2.19	2.60	2.26	2.96	2.81	2.25	2.40	2.42
Livestock	3.61	3.54	3.52	3.49	3.57	3.61	3.62	3.66	3.65	3.74
Leaching/Runoff	2.82	2.47	2.58	2.84	2.64	3.12	3.02	2.66	2.75	2.80
Total	**14.93**	**13.35**	**13.68**	**14.69**	**14.04**	**15.93**	**15.51**	**14.10**	**14.45**	**14.74**

Note: Totals may not sum due to independent rounding.

Methodology

Nitrous oxide emissions from agricultural soil management were estimated using methods found in the EIIP guidance (EIIP 1999) and the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997), as amended by the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). These are also the methods employed in the U.S. Inventory (EPA 2001). There are three types of N$_2$O emissions from soils: (1) direct emissions from managed soils, where the N$_2$O is emitted from nitrogen-related cropping practices; (2) direct emissions from livestock manure deposited on pasture, range, and paddock; and (3) indirect emissions, where nitrogen-containing compounds are released to the atmosphere or groundwater, and— following denitrification/nitrification—are emitted as N$_2$O. Sources of direct emissions from managed soils include fertilizer and manure use in cropping, application of crop residues to soils, production of nitrogen-fixing crops, and cultivation of histosols.

Indirect emissions arise from fertilizer use, livestock manure, and nitrogen-containing leachate and runoff. This section describes emission calculation methodologies for each of these subsectors.

Direct N₂O Emissions from Managed Soils

Estimates of direct N_2O emissions from managed soils were based on the amount of nitrogen deposited annually on managed soils in the following forms: (1) commercial fertilizer application (including sewage sludge); (2) manure application from daily spread operations; (3) production of nitrogen-fixing crops; (4) nitrogen returned to soils through the application of crop residues; and (5) cultivation of high-organic content soils (histosols). Estimates from each of these sources of nitrogen were summed to develop a total estimate for direct emissions from managed agricultural soils.

Data for the total nitrogen load of both synthetic and organic commercial fertilizers used annually were available at the state level. To avoid double-counting the emissions from manure, organic fertilizer consumption data were adjusted to represent only non-manure organic fertilizers. Non-manure organic fertilizer consumption was then multiplied by its average nitrogen content (EIIP 1999).

Following methodologies used in the U.S. Inventory (EPA 2001), the nitrogen in manure was calculated for each animal type. Percentages of California livestock manure deposited in daily spread operations were taken from the U.S. Inventory (EPA 2001). Manure nitrogen is equal to the product of the animal population, the TAM, and the Kjeldahl nitrogen emission factor,[3] according to the following equation:

Amount of Nitrogen in Manure = Animal Population (head) x TAM (kg/head) x Kjeldahl nitrogen emission factor (kg N/1000 kg animal mass/day) x 365 days/year

The amount of nitrogen added to soils by nitrogen-fixing crops was calculated as the product of legume production, the fraction of dry matter, and the nitrogen content of the aboveground biomass. The production mass was adjusted to include the residue. These calculations are reflected in the following equation, and key assumptions are presented in Table 4-20 (EPA 2001):

Amount of Nitrogen Returned to Soils from N-Fixing Crops (kg N) =
Crop Production (kg) x (1 + Ratio of Residue Mass to Crop Mass (kg residue/kg crop)) x
Dry Matter Fraction of Residue (kg dm/kg residue) x Fraction of Residue Applied x
Nitrogen Content (kg N/kg dm)

When much of the crop mass for a specific crop is not harvested (e.g., the stalks and cobs of corn), and is instead left on the field, the nitrogen in these "crop residues" is returned to the soil. Nitrogen from residues of corn, wheat, barley, sorghum, oats, rye, rice, soybeans, peanuts, beans, and peas were calculated as the product of the crop production, the mass ratio of residue to crop, the dry matter fraction of the crop residue, the amount of residue that is not burned, and the nitrogen content of the residue.

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[3] Kjeldahl nitrogen refers to amount of nitrogen that is either organically bound or in the form of ammonia.

Table 4-20: Key Assumptions for Nitrogen-Fixing Crop Production and Crop Residue Application

Crop	Residue: Crop Mass Ratio	Residue Dry Matter Fraction	Fraction Residue Applied	N Content of Residue (kg N/kg dm)
Alfalfa	0.0	0.85	0.9	0.0300
Corn	1.0	0.91	0.9	0.0058
Wheat	1.3	0.93	0.9	0.0062
Barley	1.2	0.93	0.9	0.0077
Sorghum	1.4	0.91	0.9	0.0108
Oats	1.3	0.92	0.9	0.0070
Rye	1.6	0.90	0.9	0.0048
Rice	1.4	0.91	1.0	0.0072
Soybeans	2.1	0.86	0.9	0.0230
Peanuts	1.0	0.90	0.9	0.0106
Dry Edible Beans	2.1	0.86	0.9	0.0062
Dry Edible Peas	1.5	0.87	0.9	0.0062

Source: EPA 2001

Note: For the derivation of activity data for nitrogen-fixing crop production, the IPCC default nitrogen content of aboveground biomass (3 percent) was used.

Estimates of annual emissions of N_2O resulting from histosol cultivation were based on the total acreage of histosols in California that are cultivated each year. These areas were multiplied by an emission factor for histosols (kg N_2O-N/ha-yr) in order to estimate emissions from this source (IPCC 2000, EIIP 1999).

Following each of these sets of calculations, the nitrogen derived from each source was classified as either volatilized or unvolatilized. Direct emissions result from nitrogen that resides in soil being transformed into atmospheric N_2O. Indirect N_2O emissions, on the other hand, involve the transport of nitrogen from the soil to another matrix (either the atmosphere or groundwater), and usually as a species other than N_2O. Emission then takes place from this intermediate matrix. Generally, unvolatilized nitrogen is the source of direct emissions; volatilized nitrogen is the source of indirect emissions.[4] One hundred percent of the nitrogen associated with crop residues, nitrogen-fixing crops, and histosols was considered unvolatilized. Ninety percent of the synthetic fertilizer nitrogen was assumed to remain unvolatilized, and eighty percent of the non-manure organic fertilizer was assumed to remain unvolatilized (IPCC 2000, EIIP 1999, EPA 2001).

To estimate the N_2O emissions from the unvolatilized nitrogen sources, the nitrogen content of each source was multiplied by an emission factor. The factor expresses the ratio of nitrogen emitted as N_2O to the total unvolatilized nitrogen added to the nitrogen cycle. For fertilizers, crop residues, and legumes, N_2O emissions are equal to 1.25 percent of the total unvolatilized nitrogen (IPCC 2000, EIIP 1999, EPA 2001). The emission factor for histosols yields a value for emissions of N_2O; therefore, it was not necessary to convert from unvolatilized nitrogen to N_2O.

Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure

Direct N_2O emissions from pasture, range, and paddock livestock manure are based on the amount of nitrogen in manure for each animal type. This value is equal to the product of the animal population, the typical animal mass (TAM), and the Kjeldahl nitrogen emission factor. This calculation is represented by the following equation:

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[4] Leachate and runoff, a source of indirect emissions, is a slightly different case. Emissions from leachate and runoff are a function of the unvolatilized nitrogen that enters groundwater.

Amount of Nitrogen in Manure (kg N/year) = Animal Population (head) x TAM (kg/head) x Kjeldahl nitrogen emission factor (kg N/1000 kg animal mass/day) x 365 (days/year)

TAM data for dairy cattle, beef cattle, swine, and poultry were taken from the U.S. Inventory (EPA 2001). TAM data for sheep, goats, and horses, and Kjeldahl nitrogen emission factors for all livestock are from the EIIP guidelines (1999). These data are presented in Table 4-21. Eighty percent of the manure that is deposited directly onto pasture, range, or paddock was estimated to be unvolatilized, and emissions from this source are equal to 2 percent of the total unvolatilized nitrogen (EPA 2001, EIIP 1999, IPCC 2000). Percentages of California livestock manure deposited on pasture, range and paddock for dairy and beef cattle, swine, and sheep were taken from the U.S. Inventory (EPA 2001); percentages for goats, horses, and poultry were extracted from the EIIP guidelines (1999).

Table 4-21: Typical Animal Mass and Kjeldahl Nitrogen Emission Factors by Animal

Animal Type	Typical Animal Mass (TAM) (kg)[a]	Kjeldahl Nitrogen (kg/day of K-N/ 1000 kg)[b]
Dairy Cows	604	0.44
Dairy Heifers	476	0.31
Feedlot Steers and Heifers	420	0.30
NOF Bulls	750	0.31
NOF Calves	159	0.30
NOF Cows	590	0.33
NOF Steers	318	0.31
NOF Heifers	420	0.31
Market Swine[c]	15 – 91	0.42 – 0.60
Breeding Swine	198	0.24
Layers[d]	1.8	0.62 – 0.83
Broilers	0.9	1.10
Turkeys	6.8	0.74
Sheep	27	0.42
Goats	64	0.45
Horses	450	0.30

[a]TAM data for dairy cattle, beef cattle, swine, and poultry are from EPA (2001). TAM data for sheep, goats, and horses are from EIIP (1999).
[b]Kjeldahl nitrogen emission factors are from EIIP (1999).
[c]TAMs and Kjeldahl nitrogen emission factors for market swine vary based on weight.
[d]Kjeldahl nitrogen emission factors for layers vary based on age group.

Indirect N$_2$O Emissions from Soils

Estimates of indirect N$_2$O emissions from soils include (1) volatilization of NH$_3$ and NO$_x$ from nitrogen deposition in fertilizer application and livestock manure; and (2) leaching and runoff of nitrogen from agricultural fields.[5] Fertilizer and manure emissions were calculated by multiplying the volatilized portion of each source's total nitrogen content by an emission factor of 1 percent. Like the factor used for determining the direct emissions, this factor reflects the ratio of nitrogen emitted as N$_2$O to total volatile nitrogen (i.e., nitrogen in the form of NO$_x$, NH$_3$, and N$_2$O). Emissions from leaching and runoff are a function of the portion of unvolatilized nitrogen from manure and fertilizers that enter groundwater. Following guidance developed by EIIP (1999) and IPCC (2000), as well as methods used in the U.S. Inventory (EPA 2001), estimates of indirect

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[5] Note that existing methods do not account for potential N$_2$O emissions due to atmospheric nitrogen deposition from non-agricultural sources.

emissions are based on the following assumptions: 30 percent of the unvolatilized nitrogen in fertilizer and manure enter leachate and runoff, and 2.5 percent of groundwater nitrogen is emitted as N_2O.

Data Sources

Fertilizer consumption data was obtained from *Fertilizing Materials Tonnage Reports*, published by the California Department of Food and Agriculture (CDFA 1992 - 2000). Crop production data were taken from *Crop Reports*, released by the California County Agricultural Commissioners (CCAC 2001). The animal population data sets used for the manure management emissions estimates were used to estimate N_2O emissions from agricultural soils as well (EPA 2001, AHC 1996, FAO 2001, USDA 200a-g, USDA 1999a-d, USDA 1998a-b, UDSA 1995a-b, USDA 1994a-b). See the section on Manure Management for further information on these data sources. Histosol cultivation acreage was estimated based on the expert judgment of two California State soil scientists (Vinson 2001, Simpson 2001). All emission factors and conversion factors can be found in the EIIP guidance (1999), IPCC guidance (2000), or the U.S. Inventory (EPA 2001).

Agricultural Residue Burning

Agricultural cropping practices result in large quantities of crop residues each year. These residues can be disposed of through a number of means: plowing crop waste back into the soil, composting waste and reapplying to the soil, landfilling, or burning. Open field burning, which is a common practice in California, is a net source of CH_4, N_2O, carbon monoxide (CO), and nitrogen oxides (NO_x). Because the carbon released in field burning is assumed to be reabsorbed the next growing season, this practice is not considered a net source of CO_2. Emissions from CO_2 are reported below (see Table 4-23), but are not included in total emissions from agricultural residue burning.

Emissions due to agricultural residue burning totaled 0.16 MMTCO$_2$ Eq. in 1999, a 25 percent increase from 1990 emissions (see Table 4-22). This increase is largely due to the increase in agricultural crop production. The production of almonds, corn, rice, and walnuts increased while the production of barley and wheat declined over the ten-year period.

Table 4-22: Emissions from Agricultural Residue Burning (10^3 MTCO$_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH$_4$	33.10	29.35	32.60	35.30	38.35	37.00	39.63	39.66	39.25	39.95
N$_2$O	91.13	81.31	90.50	99.62	110.06	106.36	111.60	112.72	111.12	115.75
Total	124.23	110.66	123.11	134.91	148.41	143.36	151.23	152.39	150.37	155.69

Note: Totals may not sum due to independent rounding.

Rice straw was the largest source of CH_4, N_2O, and CO_2 emissions in California (see Table 4-23). Less significant CH_4 emissions resulted from burning almonds, wheat, and walnuts. After rice, almonds and walnuts were the next largest source of N_2O emissions. Recognizing that rice burning is a significant source of greenhouse gas emissions, the state has adopted measures to limit burning of rice residues. Agricultural burning of other crops is also undergoing systematic curtailment (Jenkins and Turn 1994).

Table 4-23: Emissions from Agricultural Residue Burning by Gas and by Crop (10^3 MTCO$_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH$_4$ Emissions										
Almonds	6	6	6	6	7	6	7	7	7	8
Barley	1	1	1	1	1	1	1	1	0	0
Corn	1	1	2	2	2	2	2	2	2	2
Rice	18	15	18	20	22	22	22	23	22	23
Walnuts	3	3	3	3	3	3	3	3	4	4
Wheat	4	3	4	4	4	3	4	4	4	3
Total	**33**	**29**	**33**	**35**	**38**	**37**	**40**	**40**	**39**	**40**
N$_2$O Emissions										
Almonds	15	15	15	15	16	16	16	16	17	19
Barley	1	1	1	1	1	1	1	1	1	0
Corn	1	1	1	1	1	1	2	2	2	2
Rice	65	57	65	73	82	80	83	84	82	86
Walnuts	6	6	6	6	6	6	6	6	7	7
Wheat	3	2	3	3	3	3	4	3	3	3
Total	**91**	**81**	**91**	**100**	**110**	**106**	**112**	**113**	**111**	**116**
CO$_2$ Emissions										
Almonds	451	429	434	453	474	458	486	484	510	553
Barley	20	17	18	18	19	18	16	13	11	8
Corn	51	48	53	57	59	60	71	78	81	72
Rice	1,221	1,068	1,224	1,379	1,558	1,503	1,564	1,593	1,546	1,621
Walnuts	155	159	159	163	165	168	167	167	173	175
Wheat	123	86	111	112	112	102	138	124	117	97
Total	**2,020**	**1,808**	**1,999**	**2,181**	**2,388**	**2,308**	**2,441**	**2,459**	**2,439**	**2,527**

Note: Totals may not sum due to independent rounding.

Methodology

The method used to estimate CH$_4$, N$_2$O, and CO$_2$ emissions from open burning of agricultural crop wastes in California was created by B.M. Jenkins and his colleagues at the University of California at Davis (Jenkins and Turn 1994, Jenkins et al. 1992). Together, Jenkins and his colleagues developed California-specific parameters for estimating criteria pollutant emissions from this source.

Jenkins et al. developed parameters for six crops—almonds, walnuts, wheat, barley, corn, and rice—which account for 97 percent of the agricultural biomass burned in California (excluding wildfires and prescribed forest burns). Crop-specific parameters include (1) residue yield, to determine the amount of residue produced, (2) burn fraction, to quantify the amount of crop residue that actually burns on the field, and (3) crop and greenhouse gas-specific emission factors.

Estimates of emissions from agricultural residue burning in California were developed by multiplying production area for each crop type by the crop-specific parameters as shown in the equation below:

Emissions = [Production Area] x [Residue Yield] x [Burn Fraction] x [Emission Factor]

Data Sources

Crop production acreage data were obtained from *Crop Reports* published by the California County Agricultural Commissioners (1990-2000). The parameters (burn fractions, residue yields, and CH_4 and CO_2 emission factors) used to estimate agricultural residue burning emissions were taken from Jenkins et al. (1992) and Jenkins and Turn (1994) (see Table 4-24). Nitrous oxide emission factors were derived from the emission factors for NO_x using the ratios of NO_x-N/N and N_2O-N/N provided in the IPCC guidelines (Jenkins and Turn 1994, IPCC/UNEP/OECD/IEA 1997).

Table 4-24: Parameters Used in Estimating Emissions from the Agricultural Waste Burned

	Almonds	Walnuts	Wheat	Barley	Corn	Rice
Burn Fraction (percent)	84%	95%	11%	7%	3%	99%
Residue Yield (ton/ha dry basis)	1.89	1.46	3.66	2.51	9.06	6.75
CH_4 Emission Factor (percent dry crop mass)	0.12%	0.16%	0.18%	0.25%	0.18%	0.08%
CO_2 Emission Factor (percent dry crop mass)	183%	164%	120%	117%	131%	117%
N_2O Emission Factor (percent dry crop mass)	0.02%	0.02%	0.01%	0.02%	0.01%	0.02%

Source: Jenkins et al. 1992, Jenkins and Turn 1994

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Chapter 5

Land-Use Change and Forestry

This section includes estimates of the net carbon dioxide (CO_2) flux caused by (1) changes in forest carbon stocks; (2) changes in agricultural soil carbon stocks, and (3) changes in yard trimming carbon stocks in landfills. Estimated total annual net CO_2 flux from land-use change and forestry in 1999 was 18.8 million metric tons of carbon dioxide equivalent (MMTCO$_2$ Eq.) (see Table 5-1). Sequestration offset 6 percent and 4 percent of total state emissions in 1990 and 1999, respectively. Over the ten-year period from 1990 to 1999, net sequestration has declined by 27 percent. This decline is primarily due to decreased area of forest land in California. When land is converted from forests to other uses, the initial loss of carbon is greater than the initial gain in carbon when land reverts to forest (Birdsey 2001).

Table 5-1: Net Carbon Flux From Land-Use Change and Forestry (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Forests	-21.16	-21.16	-17.27	-17.27	-17.27	-17.27	-17.27	-17.27	-17.27	-17.27
Agricultural Soils	0.06	0.09	0.11	0.07	0.16	0.27	0.27	0.35	0.25	0.33
Landfilled Yard Trimmings	-4.49	-4.14	-3.81	-3.49	-3.18	-2.89	-2.61	-2.34	-2.11	-1.85
Total	**-25.58**	**-25.21**	**-20.97**	**-20.68**	**-20.29**	**-19.88**	**-19.61**	**-19.26**	**-19.13**	**-18.79**

Note: Totals may not sum due to independent rounding.

Changes in Forest Carbon Stocks

The 38.5 million acres of forested land in California cover 39 percent of the land base. In recent decades, area of forested land has declined slightly (Birdsey 2001). Overall, California's forests were a net sink of CO_2–indicating that forest growth has been occurring at a faster pace than forest clearing, harvests, and decomposition. In 1999, net sequestration due to forest carbon stocks was 17.3 MMTCO$_2$ Eq., 18 percent lower than net sequestration in 1990. Table 5-2 presents the estimates of forest carbon sequestration by forest component.

Table 5-2: Net Carbon Flux From Forest Carbon Stocks (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Biomass	-18.5	-18.5	-18.7	-18.7	-18.7	-18.7	-18.7	-18.7	-18.7	-18.7
Forest Floor & Course Woody Debris	5.2	5.2	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
Soils	3.1	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Wood Products and Landfills	-11.0	-11.0	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4
Total	**-21.2**	**-21.2**	**-17.3**	**-17.3**	**-17.3**	**-17.3**	**-17.3**	**-17.3**	**-17.3**	**-17.3**

Source: Birdsey and Lewis 2001; 1997 carbon flux estimates are used as a proxy for 1998 and 1999.
Note: Negative values indicate net sequestration. Lightly shaded areas indicate values based on a combination of historical data and projections. Totals may not sum due to independent rounding.

In the state, forest carbon flux offset 17.3 MMTCO$_2$ Eq., 4 percent, of gross 1999 emissions. Forest carbon flux accounted for 83 percent and 92 percent of state sinks in 1990 and 1999, respectively. Forest carbon flux accounted for an increased proportion of state sinks as carbon storage from landfilled yard trimmings decreased from 1990 through 1999.

Storage in live biomass accounted for the majority of sequestration during the period from 1990 through 1999. Wood products and landfills—including the wood removed from the forest for product manufacture or use as fuelwood and discarded wood products in landfills—also resulted in net sequestration of carbon. Soils were a net source of emissions—the high rate of loss associated with land use conversion outweighed the slower pace of carbon accumulation in the land that remained forested. The forest floor also acted as a net source of emissions in California, though the reported decrease in carbon could be due to the reclassification of forest types and lack of consistent age class information.

Between 1987 and 1997, total carbon stocks increased, mostly due to increases in ponderosa pine and other softwood forest types. Carbon stocks for fir-spruce, chaparral, and pinyon-juniper decreased during the period (see Table 5-3).

Table 5-3: Area of Forested Land by Forest Type (1,000 acres)

Forest Type	1987	1992	1997	Average Annual Change 1987-1992	1992-1997	1987-1997
Douglas-fir	1,718	2,060	2,402	68	68	68
Ponderosa pine	5,717	6,830	7,944	223	223	223
Western white pine	5	186	366	36	36	36
Fir-spruce	7,810	6,007	4,205	-361	-361	-361
Hemlock-Sitka spruce	59	41	24	-3	-3	-3
Larch	0	0	0	0	0	0
Lodgepole pine	952	702	452	-50	-50	-50
Redwood	1,270	1,090	910	-36	-36	-36
Other Hardwoods	9,781	9,327	8,873	-91	-91	-91
Other forest types	1,229	3,905	6,581	535	535	535
Pinyon-juniper	2,699	2,161	1,622	-108	-108	-108
Chaparral	8,021	6,424	4,827	-319	-319	-319
Non-stocked	120	231	341	22	22	22
Total	**39,381**	**38,964**	**38,547**	**-83**	**-83**	**-83**

Source: Birdsey and Lewis 2001
Note: Totals may not sum due to independent rounding.

Methodology

Carbon sequestration and emissions associated with Land-Use Change and Forestry are characterized through the application of a U.S. Department of Agriculture, Forest Service (USDA-FS) model that tracks forest carbon flows related to tree growth, forest removals, and decomposition. The model partitions ecosystem carbon (C) into three separate components (Birdsey and Lewis 2001):

- biomass, which includes all aboveground and belowground portions of all live and dead trees and understory vegetation;
- forest floor, which includes all dead organic matter above the mineral soil horizons except standing dead trees; and
- soil, which includes all organic C in the mineral horizons to a depth of 1 m.

The carbon estimates for the forest components are based on forest age, type, productivity class, and land-use history. These parameters characterize the forest and ecosystem carbon dynamics, as well as the understory, soil, and forest floor models that best describe carbon flows. Additionally, the model tracks carbon in forest products (e.g., lumber, plywood, paper), accounting for the C sequestered during products' lifetimes, as well as carbon stored (net of degradation) in landfills. See Figure 5-1 for an illustration of forest sector carbon flows.

Figure 5-1: Forest Sector Carbon Flows
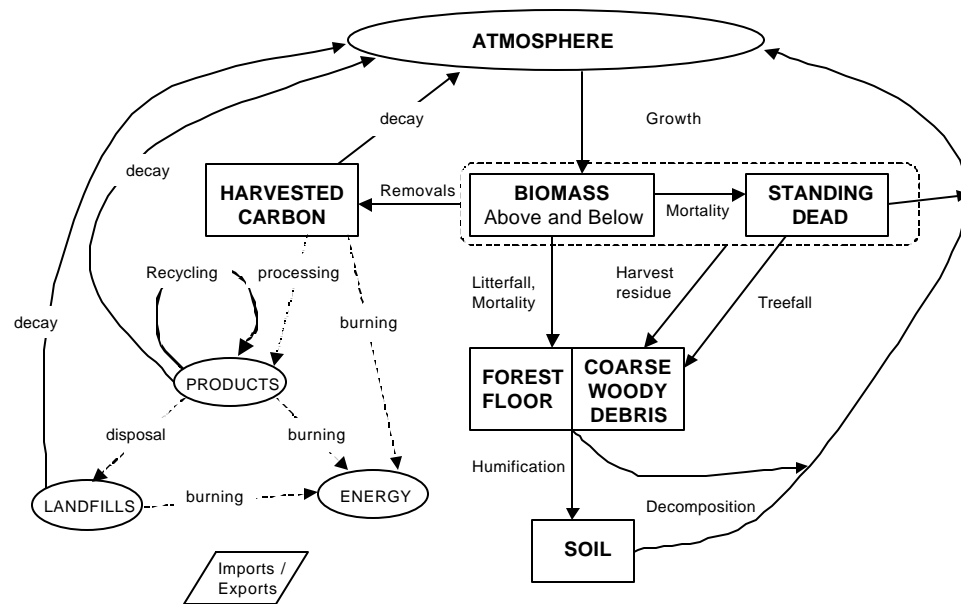
Source: Birdsey and Lewis 2001

Estimates of carbon stocks are not made for each year; rather, they are simulated for five-year intervals (1987, 1992, and 1997). Data for 1992 was not updated for California. Thus, 1992 carbon stocks were estimated through interpolation using 1987 and 1997 data. For any year bracketed by these dates, the change in carbon stored over the interval, divided by five years, represents the annual flux. Birdsey and Lewis' estimates do not include 1998 and 1999; therefore, for the purpose of this inventory, carbon flux was assumed to remain constant from 1997 through 1999.

Data Sources

The forest carbon model used to develop these estimates is maintained by the USDA-FS and is detailed in the working paper entitled "Carbon Stock Changes in California's Forests, 1987-1997" (Birdsey and Lewis 2001). Data sources and methods used to develop California-specific estimates are described in this working paper. Inventory data was obtained from the Resource Planning Act (RPA) Assessments for 1987 and 1997. Areas of forested land by class and by forest type appear above in Table 5-3 and below in Table 5-4. Birdsey (1996) explains the methods used to estimate forest carbon storage for the components of ecosystem carbon; Row and Phelps (1991) work is the basis for estimates of carbon stored in forest products and landfills; and Plantinga and Birdsey (1993) and Birdsey (1992) explain the methods used to estimate soil carbon.

Table 5-4: Area of Forested Land by Land Class (1,000 acres)

Land Class	1987	1992	1997	Average Annual Change 1987-1992	1992-1997	1987-1997
Timberland	16,712	17,332	17,952	124	124	124
Other forest land	17,766	16,196	14,626	-314	-314	-314
Reserved timberland	4,903	5,435	5,968	107	107	107
Total	**39,381**	**38,964**	**38,547**	**-83**	**-83**	**-83**

Source: Birdsey and Lewis 2001
Note: Totals may not sum due to independent rounding.

Changes in Agricultural Soil Carbon Stocks

Changes in agricultural soil carbon stocks include emissions due to the application of crushed limestone and dolomite to agricultural soils as well as changes in mineral and organic soil carbon stocks. Lime, in the form of crushed limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), is commonly added to agricultural soils to inhibit acidification. These compounds degrade once they come in contact with acid soils, generating CO_2 emissions. The rate of degradation is dependent on soil conditions and the type of mineral being applied.

Data on mineral and organic soils were not available for California; therefore, carbon fluxes from these soils could not be included in the inventory. The California Energy Commission is considering options for estimating carbon fluxes from these soils in future inventories.

Emissions due to liming of agricultural soils totaled 0.1 MMTCO$_2$ Eq. in 1990 and 0.3 MMTCO$_2$ Eq. in 1999 (see Table 5-5). The increase in annual emissions from liming is due to increasing amounts of lime applied to agricultural soils.

Table 5-5: Net CO$_2$ Flux From Agricultural Soils (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Mineral Soils	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Organic Soils	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Liming of Soils	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.3	0.3
Total	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.3**	**0.3**	**0.4**	**0.3**	**0.3**

Note: Lightly shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only.

Methodology

Liming of Soils

Carbon dioxide emissions associated with the degradation of limestone and dolomite on agricultural soils were calculated by multiplying the annual amounts of limestone and dolomite applied by their respective CO_2 emission factors (0.120 metric ton C/metric ton limestone, 0.130 metric ton C/metric ton dolomite). As noted in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*, "the default emission factor for dolomite provided in the Workbook volume of the *Revised 1996 Intergovernmental Panel on Climate Change Guidelines* (IPCC/UNEP/OECD/IEA 1997) is incorrect. The value provided is 0.122 metric ton carbon/metric ton of dolomite; the correct value is 0.130 metric ton carbon/metric ton of dolomite" (EPA 2001). These emission factors assume that all of the carbon in these materials evolves as CO_2 in the same year in which the minerals are applied (EPA 2001).

The annual application rates of limestone and dolomite were derived from estimates provided by the California Department of Food and Agriculture (CDFA 2001). CDFA reports total lime used on agricultural soils. No data were available for 1990 and 1991. Total lime use in those years was derived using regression analysis.

Total lime use is further broken out into limestone and dolomite used for agriculture. This breakout was calculated by applying the proportions of total limestone and dolomite sold or used in California to total agricultural lime use. Industry statistics in the *Minerals Yearbook* and *Mineral Industry Surveys* provided values for the total limestone and dolomite sold or used in California (Tepordei 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001; USGS 2001). USGS (U.S. Bureau of Mines prior to 1997) obtained this data by surveying crushed stone manufacturers. Data on the total limestone and dolomite sold or used in California were not available in 1990, 1992, and 2000. Data from 1991 to 1999 was used to extrapolate total consumption for 1990 and to interpolate total consumption for 1992.

Data Sources

Liming of Soils

Amounts of total lime used in agriculture were obtained from the California Department of Food and Agriculture (CDFA 2001). Values for the total limestone and dolomite sold or used in California were found in the *Minerals Yearbook*, published by the Bureau of Mines through 1996 and by the U.S. Geological Survey from 1997 to the present.

Changes in Yard Trimming Carbon Stocks in Landfills

Landfilled yard trimmings, like landfilled forest products, can store carbon indefinitely. In California, yard trimmings (i.e., grass clippings, leaves, branches) comprised approximately 15 percent of the total waste disposed in 1990 and 10 percent in 1999 (CIWMB 2001). The decreased disposal rate for yard trimmings on a national level is typically attributed to programs banning or discouraging disposal, coupled with a significant increase in the number of composting facilities. The decrease in the yard trimmings landfill disposal rate has resulted in a significant decrease in the rate of landfill carbon storage from 4.5 MMTCO$_2$ Eq. in 1990 to 1.9 MMTCO$_2$ Eq. in 1999 (see Table 5-6).

Carbon flux associated with landfilled yard trimmings represented roughly 10 percent of state sinks, and was responsible for offsetting 0.4 percent of gross state emissions.

Table 5-6: Net Carbon Flux From Landfilled Yard Trimmings (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Landfilled Yard Trimmings	-4.5	-4.1	-3.8	-3.5	-3.2	-2.9	-2.6	-2.3	-2.1	-1.9

Methodology

Carbon storage in landfilled yard trimmings is calculated using the same methods as are used to develop national estimates for the U.S. Inventory:

"The methodology for estimating carbon storage is based on a life cycle analysis of greenhouse gas emissions and sinks associated with solid waste management (EPA 1998). According to this methodology, carbon storage is the product of the mass of yard trimmings disposed, on a wet weight basis, and a storage factor. The storage factor, which is the fraction of total carbon that is assumed to be stored permanently, is based on a series of experiments designed to evaluate methane generation and residual organic material in landfills (Barlaz 1998). These experiments analyzed grass, leaves, branches, and other materials, and were designed to promote biodegradation by providing ample moisture and nutrients."

"This analysis assumes that the composition of yard trimmings consists of 50 percent grass clippings, 25 percent leaves, and 25 percent branches on a wet weight basis. Each component uses a different storage factor. The weighted average carbon storage factor is 0.23 (metric ton of carbon stored indefinitely per metric ton [wet weight] of yard trimmings landfilled), as shown in Table [5-7]." (EPA 2001)

Table 5-7: Composition of Yard Trimmings in MSW and Carbon Storage Factor (metric ton of carbon/ metric ton yard trimmings)

Component	Percent	Storage Factor
Grass	50%	0.13
Leaves	25%	0.43
Branches	25%	0.23
Total/Weighted Average	**100%**	**0.23**

Data Sources

The yard trimmings discard rate was obtained from the California Integrated Waste Management Board (CIWMB 2001). The report provides estimates for the years 1990 and 1999. Estimates in these years were used to interpolate disposal rates for the years from 1991 through 1998.

The CIWMB report does not specify tons of discarded materials landfilled and combusted. The percentages of waste combusted and landfilled in California were taken from *Biocycle's* annual report "The State of Garbage in America" (Biocycle 1998, 1999, 2000). These percentages were applied to yard trimmings disposed to determine the proportion of discards managed in landfills.

Carbon storage factors were obtained from an EPA report on life-cycle greenhouse gas emissions from waste management (EPA 1998).

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Chapter 6

Waste

Waste management in California results in methane (CH_4) emissions from landfills, carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions from waste combustion, and CH_4 and N_2O emissions from wastewater treatment. Because methodologies are not currently available to develop a complete estimate of N_2O emissions from wastewater, this inventory reflects the portion of wastewater N_2O emissions attributable to human sewage.

In total, waste management and treatment activities in California emitted 16.0 million metric tons of carbon dioxide equivalent (MMTCO$_2$ Eq.) of greenhouse gas emissions in 1999, an 18 percent decline since 1990 (see Table 6-1). Landfills accounted for the majority (86 percent) of waste emissions and were responsible for the overall trend in sectoral emissions. Waste sector emissions in California represented 4 percent of the State's gross greenhouse gas emissions in 1999 and 6 percent of national waste sector emissions in 1999.

Table 6-1: Emissions from Waste (MMTCO$_2$ Eq.)

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH$_4$	**18.21**	**18.30**	**18.57**	**18.64**	**18.39**	**17.92**	**16.43**	**15.60**	**13.64**	**14.56**
Landfills	16.95	17.02	17.26	17.32	17.06	16.58	15.09	14.24	12.27	13.17
Wastewater Treatment	1.27	1.28	1.30	1.32	1.33	1.33	1.34	1.36	1.37	1.39
N$_2$O	**0.96**	**0.89**	**0.88**	**0.96**	**0.89**	**0.96**	**0.93**	**1.03**	**1.06**	**1.08**
Human Sewage	0.93	0.87	0.85	0.94	0.86	0.93	0.91	1.00	1.04	1.05
Waste Combustion	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
CO$_2$	**0.30**	**0.30**	**0.31**	**0.31**	**0.32**	**0.32**	**0.32**	**0.31**	**0.30**	**0.31**
Waste Combustion	0.30	0.30	0.31	0.31	0.32	0.32	0.32	0.31	0.30	0.31
Total	**19.47**	**19.49**	**19.75**	**19.91**	**19.59**	**19.19**	**17.68**	**16.93**	**15.01**	**15.95**

Note: Totals may not sum due to independent rounding.

Landfills

Landfills are the largest source of anthropogenic CH_4 emissions in California. In 1999, emissions were 13.2 MMTCO$_2$ Eq., approximately 6 percent of national emissions from landfills. Municipal solid waste (MSW) landfills accounted for 93 percent of total CH_4 generated, with industrial landfills accounting for the remainder.

Methane emissions are the result of the decomposition of organic materials (e.g., paper, food scraps, and yard trimmings) in landfills. The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001) describes the CH_4 production process as follows:

"This decomposition process is a natural mechanism through which microorganisms derive energy. After being placed in a landfill, organic waste is initially digested by aerobic bacteria. After the oxygen supply has been depleted, the remaining waste is consumed by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. Methane-producing anaerobic bacteria convert these fermentation products into stabilized organic materials and biogas consisting of approximately 50 percent CO_2 and 50 percent CH_4, by volume.

Methane production typically begins one or two years after waste disposal in a landfill and may last from 10 to 60 years."

While there is variability in the duration of CH_4 generation, the U.S. Inventory and the EPA's Landfill Methane Outreach Program assume that CH_4 is emitted over a 30-year time horizon.

Factors influencing landfill CH_4 emissions include the quantity of solid waste in landfills (waste-in-place) that is less than thirty years old, the composition of this waste, the quantity of CH_4 recovered for energy projects or flared, and the amount of CH_4 oxidized. The total amount of waste-in-place in California landfills increased from 760 million tons in 1990 to 932 million tons in 1999, a gain of 23 percent. This increase resulted in an increase in CH_4 generation from 27.1 MMTCO$_2$ Eq. in 1990 to 31.8 MMTCO$_2$ Eq. in 1999, as shown in Table 6-2. The amount of CH_4 recovered, meanwhile, increased from 7.6 MMTCO$_2$ Eq. to 15.7 MMTCO$_2$ Eq. during this period.

The net effect of these two trends – the relatively modest increase in CH_4 generation coupled with the large increase in recovery – was a 22 percent decrease in net landfill emissions over the ten-year period. This is a significantly larger decrease, in percentage terms, than the 1 percent decrease that occurred for the United States as a whole during this period. This difference can be attributed to the rapid growth of CH_4 recovery in California, which increased at a significantly higher rate than recovery in the United States (EPA 2001). Waste-in-place and CH_4 generation in California and the United States increased at similar rates.

Table 6-2: Emissions of CH$_4$ from Landfills (MMTCO$_2$ Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Potential Emissions	**27.1**	**27.8**	**28.4**	**29.0**	**29.5**	**30.0**	**30.4**	**30.9**	**31.4**	**31.8**
MSW Generation	25.3	25.9	26.5	27.1	27.6	28.0	28.5	28.9	29.3	29.7
Small Landfills	4.2	4.3	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2
Large Landfills	21.1	21.6	22.1	22.5	22.9	23.2	23.6	23.9	24.2	24.6
Industrial Generation	1.8	1.8	1.9	1.9	1.9	2.0	2.0	2.0	2.1	2.1
Emissions Recovered	**-7.6**	**-8.1**	**-8.5**	**-8.9**	**-9.7**	**-10.6**	**-12.5**	**-13.8**	**-16.2**	**-15.7**
Landfill Gas-to-Energy	-6.3	-6.3	-6.3	-6.8	-7.8	-7.8	-7.9	-8.3	-8.7	-9.4
Flare	-1.3	-1.8	-2.1	-2.1	-1.9	-2.8	-4.6	-5.5	-7.5	-6.3
Oxidation	-2.5	-2.6	-2.7	-2.7	-2.8	-2.8	-2.8	-2.9	-2.9	-3.0
Net Emissions	**16.9**	**17.0**	**17.3**	**17.3**	**17.1**	**16.6**	**15.1**	**14.2**	**12.3**	**13.2**

Note: Totals may not sum due to independent rounding.

Methodology

As per the *EIIP Volume VIII: Estimating Greenhouse Gas Emissions* (EIIP 1999), CH_4 emissions from landfills were estimated as the total amount of CH_4 produced from municipal landfills, plus the CH_4 produced by industrial landfills, minus the CH_4 recovered and combusted, minus the CH_4 oxidized before being released into the atmosphere. In accordance with the EIIP Guidelines, the following steps were taken to estimate landfill CH_4 emissions in California:

Step 1: Estimate Total Waste-In-Place (WIP) at Municipal Landfills

Total waste-in-place was calculated as the sum of waste disposal over a thirty-year period. Waste disposal data for 1990 through 1999 (shown in Table 6-3) were previously available from California records (CIWMB 2001). Waste disposal from 1960 to 1989 was estimated by multiplying per capita disposal by California population estimates (CA DOF 2001). Since data on per capita disposal were unavailable prior to

1990, the 1990 estimate of California per capita disposal was adjusted to the years 1961 to 1989 using national growth rates in per capita disposal over this period (EPA 1999a, U.S. Census Bureau 2000).

Step 2: Estimate Total Methane Generation

The estimate of total CH_4 generation was calculated as the sum of CH_4 generation from small and large municipal landfills, plus industrial landfills. In order to estimate generation from municipal landfills, the following information was needed: (1) the amount of WIP in small versus large landfills, and (2) rainfall in California. In California, 86 percent of the waste landfilled was assumed to be disposed at large landfills, which are defined as having more than 1.1 million tons of WIP. The remaining 14 percent was assumed to be disposed at small landfills (EIIP 1999). California was classified as an arid state because it receives less than 25 inches of rain per year (EIIP 1999).

Small Landfills
Using EIIP's suggested equations for estimating CH_4 generation from small landfills in arid climates, a factor of 0.27 was multiplied by WIP at small landfills to estimate generation in cubic feet/day. To obtain this estimate in tons per year, a conversion factor of 0.0077 was used (EIIP 1999). These steps are summarized in the following equation:

$$CH_{4\,Small} \text{ (tons } CH_4/yr) = WIP_{Small} \text{ (tons) x } \frac{0.27 \text{ ft}^3/\text{day}}{\text{ton}} \text{ x } \frac{0.0077 \text{ tons } CH_4/yr}{\text{ft}^3/\text{day}}$$

Where: $WIP_{Small} = WIP_{Total}$ x 14 percent

Large Landfills
To estimate CH_4 generation at large landfills, it was first necessary to determine the average WIP per large landfill, calculated as the total WIP from large landfills divided by the number of large landfills. This estimate was then entered into the following equation (EIIP 1999):

$$CH_{4\,Large} \text{ (tons } CH_4/yr) = N \text{ x } [417,957 + [0.16 \text{ x (Ave } WIP_{Large} \text{ (tons)}] \text{ x } \frac{0.0077 \text{ tons} CH_4/yr}{\text{ft}^3/\text{day}}$$

Where: N = Number of large landfills in California

Ave. $WIP_{Large} = WIP_{Large} / N$

$WIP_{Large} = WIP_{Total}$ x 86 percent

Industrial Landfills
Methane generation from industrial landfills was estimated as 7 percent of total CH_4 generation from municipal landfills, in accordance with the EIIP guidelines (1999).

Step 3: Estimate and Adjust for Methane Recovery and Oxidation

The final step in estimating net CH_4 emissions from California landfills was to adjust for the amount of CH_4 that was either: (1) recovered, in either a flaring or landfill gas-to-energy (LFGTE) project; or (2) oxidized before being released into the atmosphere.

Methane Recovery

The amount of CH_4 recovered through flaring or LFGTE projects was estimated using data and methods presented in the U.S. Inventory (EPA 2001a). Flare estimates were based on confidential sales data collected from flare equipment vendors on an annual basis. Because these data are collected as confidential business information (CBI), emission reductions for California were extracted for the state as a whole, and not for individual landfills. Recovery through LFGTE projects was estimated using a state-specific database compiled by the EPA's Landfill Methane Outreach Program (LMOP) (EPA 1999). The methodology used to estimate CH_4 recovery for flaring and LFGTE is described in more detail in the U.S. Inventory (EPA 2001).

Oxidation
The amount of CH_4 oxidized was assumed to be 10 percent of CH_4 generated (EIIP 1999).

Data Sources

California landfill disposal data for 1990 through 1999, shown in Table 6-3, were taken directly from the California Integrated Waste Management Board's *Landfill Tonnage Reports* (CIWMB 2001). These data, originally reported by county, were aggregated to reflect state disposal. Waste disposal estimates for 1960 through 1989 were calculated using California population data from the State of California Department of Finance (CA DOF 2001), U.S population data from the U.S. Census Bureau (U.S. Census Bureau 2000), and national per capita landfilled information from the *Characterization of Municipal Solid Waste in the United States: 1998 Update* (EPA 1999a). The number of large landfills was estimated using LMOP data and the fractions of large and small landfills in California were taken from the EIIP guidance (EPA 1999b, EIIP 1999). Estimates of CH_4 recovered through flaring were taken directly from the U.S. Inventory flare estimates (EPA 2001). Data on CH_4 recovered through LFGTE were obtained from the LMOP database.

Table 6-3: California Waste Disposal Data 1990-1999 (million tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Waste Disposed	40.1	36.5	36.0	34.6	34.4	33.6	32.9	33.7	35.6	35.5

Source: CIWMB 2001

Waste Combustion

During combustion of municipal solid waste (MSW), organic materials are converted to CO_2. According to the Intergovernmental Panel on Climate Change (IPCC) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, inventories should only account for the CO_2 resulting from combustion of those organic materials that are of fossil origin (i.e., plastic, synthetic rubber and synthetic fibers) (IPCC/UNEP/OECD/IEA1997). Carbon dioxide emitted from combustion of organic wastes that are of biogenic origin (i.e., paper, food scraps, yard trimmings) are considered part of the natural carbon cycle. Therefore, this section excludes these emissions. In addition, this section provides estimates of N_2O emissions resulting from combustion.

In California, there was little variation in CO_2 and N_2O emissions from MSW combustion between 1990 and 1999, as shown in Table 6-4. Nitrous oxide emissions

stayed virtually constant at 0.02 MMTCO$_2$ Eq. per year, while CO$_2$ emissions increased slightly, rising from 0.30 MMTCO$_2$ Eq in 1990 to 0.31 MMTCO$_2$ Eq in 1999. In 1999, California emissions of CO$_2$ and N$_2$O from waste combustion accounted for approximately 1 and 10 percent, respectively, of corresponding national emissions.

Table 6-4: Emissions of N$_2$O and CO$_2$ from Waste Combustion (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
N$_2$O	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
CO$_2$	0.30	0.30	0.31	0.31	0.32	0.32	0.32	0.31	0.30	0.31

Methodology

The methodology used to estimate greenhouse gas emissions from waste combustion was based on the EIIP guidelines (EIIP 1999). Separate calculations were used to estimate CO$_2$ and N$_2$O emissions.

Non-biogenic CO$_2$ Emissions from Waste Combustion

To estimate non-biogenic CO$_2$ emissions, the amount of waste combusted was multiplied by a factor of 0.40 short tons of CO$_2$ per short ton of MSW combusted to obtain emissions in short tons. This estimate was then converted to metric tons using the ratio of 0.9072 metric tons per short ton. These steps are summarized in the following equation (EIIP 1999):

$$\text{MTCO}_2 \text{ Eq.} = \text{MSW (short tons)} \times \frac{0.40 \text{ short tons CO}_2}{\text{MSW (short tons)}} \times \frac{0.9072 \text{ MT}}{\text{short ton}}$$

Where: MSW = tons of MSW combusted

Nitrous Oxide Emissions from Waste Combustion

To estimate N$_2$O emissions from combustion of municipal solid waste, the amount of waste combusted was multiplied by a factor of 0.0001 short tons of N$_2$O per short ton of municipal waste combusted. This quantity was then converted to metric tons of CO$_2$ equivalent using the ratio of 0.9072 metric tons per short ton and the global warming potential (GWP) for N$_2$O, which is 310. These steps are summarized in the following equation (EIIP 1999):

$$\text{MTCO}_2 \text{ Eq.} = \text{MSW (short tons)} \times \frac{0.0001 \text{ tons N}_2\text{O}}{\text{MSW (short tons)}} \times \frac{0.9072 \text{ MT}}{\text{short ton}} \times 310$$

Where: MSW = tons of MSW combusted

Data Sources

Combustion data for 1995 through 2000 were obtained from the California Integrated Waste Management Board's Disposal Reporting System (CIWMB 2001). Data for 1990 through 1994 were acquired through phone conversations with officials at the three permitted incineration sites operating in California during those years (Foley 2001, Simsko 2001, and Healey 2001). The total combustion estimates for 1990 to 1999 are shown in Table 6-5.

Table 6-5: Waste Combusted (metric tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
MSW Combusted	746,038	742,273	778,530	779,405	795,610	793,680	794,968	765,508	762,194	774,895

Source: CIWMB 2001, Foley 2001, Simsko 2001, Healey 2001

Municipal Wastewater

Methane is produced by the anaerobic degradation of organic material in wastewater. The organic content of wastewater is expressed as the biochemical oxygen demand (BOD). Generally, wastewater with higher BOD concentrations will produce more CH_4 than wastewater with lower BOD concentrations (EPA 2001).

In 1999, CH_4 emissions from domestic wastewater treatment in California were 1.39 MMTCO$_2$ Eq. Emissions have increased by approximately 9 percent since 1990, in response to the increase in state population over this period. Table 6-6 provides emission estimates for the period 1990 through 1999 from domestic wastewater treatment in California.

Table 6-6: CH_4 Emissions from Wastewater Treatment in California (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Wastewater Treatment	1.27	1.28	1.30	1.32	1.33	1.33	1.34	1.36	1.37	1.39

Methodology

Methane emissions from wastewater were estimated using the following equation taken from *EIIP Volume VIII, Estimating Greenhouse Gas Emissions* (1999):

$$CH_4 \ Emissions = State \ Population \times D \times FTA \times EF$$

Where: D = Organic Load in BOD per person (Default = 6 x 10^{-8} Gg BOD/person/day)
FTA = Fraction of BOD that degrades anaerobically (Default = 15 percent)
EF = Emission Factor (Default = 0.6 Gg CH_4/Gg BOD)

To estimate emissions from wastewater, the total state population was multiplied by the wastewater BOD generation rate to obtain the daily BOD generated. The daily BOD generated was then multiplied by the fraction of BOD metabolized anaerobically and by the CH_4 emission factor, to obtain total CH_4 emissions. The result was then multiplied by 365 days to obtain annual estimates of CH_4 from wastewater treatment. It was assumed that no CH_4 emissions were recovered in California.

Data Sources

Population data for 1990 through 2000 were obtained from the California Department of Finance (CA DOF 2001). Organic load and CH_4 emission factors are based on the IPCC guideline defaults (2000), while the fraction of BOD treated anaerobically is taken from the EIIP guidance (1999).

Human Sewage

Nitrous oxide is a product of nitrification and denitrification processes that occur naturally in domestic and industrial wastewater containing nitrogen-rich organic matter. Nitrification converts ammonium (NH_4^+) into nitrate (NO_3^-) through an aerobic process, while denitrification occurs anaerobically and converts NO_3^- to N_2O.

Table 6-7 provides emission estimates for the period 1990 through 1999 from human sewage in California. In 1999, N_2O emissions from human sewage were 1.05 MMTCO$_2$ Eq. Emissions have increased by approximately 13 percent since 1990, due to both the increases in state population and the per capita protein intake.

These data assume that not all sewage nitrogen is discharged into aquatic environments. A certain amount is also applied to soils via sewage sludge applications. The N_2O estimates presented here account for the amount of nitrogen in sewage sludge applied to soils. Sewage sludge related emissions estimates are covered in the "Agricultural Soil Management" chapter.

Table 6-7: N$_2$O Emissions from Human Sewage in California (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Human Sewage	0.93	0.87	0.85	0.94	0.86	0.93	0.91	1.00	1.04	1.05

Methodology

Nitrous oxide emissions from sewage in wastewater were estimated using the following equation taken from the EIIP guidance (EIIP 1999):

$$N_2O \ Emissions = \ Protein \times \ Frac_{NPR} \times \ State \ Population \times \ EF$$

Where: Protein = Annual per capita protein consumption
$Frac_{NPR}$ = Fraction of nitrogen in protein (percent)
EF = Emission factor (kg N_2O-N/kg sewage-N produced)

N_2O-N emissions from human sewage were estimated by multiplying the annual per capita consumption of protein by (1) the fraction of nitrogen in protein, (2) state population estimates and (3) an N_2O emission factor.

Data Sources

Population data for 1990 through 2000 were obtained from the California Department of Finance (CA DOF 2001). Annual per capita protein intake data was taken from the U.S. Inventory (EPA 2001). California State average protein consumption was assumed to be consistent with national levels. The fraction of nitrogen in protein, as well as, the N_2O emission factor was obtained from IPCC (2000).

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Chapter 7

California Emissions in Context

The purpose of this chapter is to compare the California anthropogenic (due to human activities) greenhouse gas (GHG) emissions with emissions from natural sources and emissions from other states, the U.S. as a whole, and countries. This chapter also includes an order of magnitude analysis of the impact of past air quality and energy policies, standards, and regulations on in-state average GHG emissions for the period 1990-1999. This chapter concludes with an analysis of emissions from out-of-state power plants serving California. In particular, the impacts that this electricity generation would have had on in-state emissions if California's power plants would have generated the electricity

Anthropogenic and Natural Emissions in California

Of the greenhouse gases reported in this inventory, only three are also produced from natural sources: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Without human intervention, there is a balance between the amount of carbon that is released and absorbed by land. Long-term natural net emissions from California lands should be close to zero. The chapter on Land-Use Change and Forestry of this inventory reports net changes in carbon pools in California lands due to human actives. For these reasons, this chapter will discuss natural emissions for methane and nitrous oxide only. Both gases are removed from the atmosphere primarily by chemical processes within the atmosphere.

Nitrous Oxide

Nitrous oxide is a potent greenhouse gas, with a 100-year global warming potential of 310. It is a stable compound that decays slowly in the atmosphere, with a long atmospheric lifetime of over 121 years. During the past two centuries, atmospheric concentrations of N_2O have risen by approximately 13 percent [IPCC, 2001] as can be seen in Figure 7-1.

Figure 7-1 Atmospheric N_2O Concentrations (ppb)
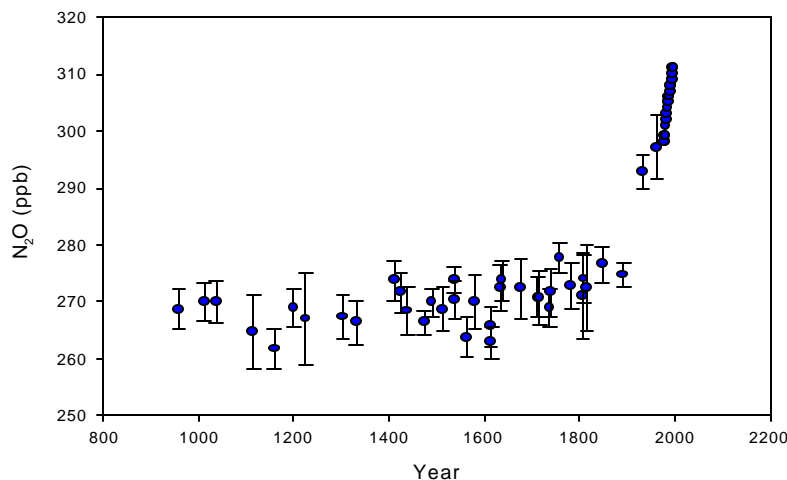
Source: Flückiger, 1999

Pre-industrial N_2O concentrations obtained from the Law Dome ice core show levels of 284.5 ppb. As seen in Figure 7-1, concentrations have increased since the industrial revolution. This increase is generally thought to result from anthropogenic sources. As evidence of this relationship, the average atmospheric concentrations of nitrous oxide are about 0.8 ppb greater in the Northern Hemisphere than in the Southern Hemisphere, consistent with the fact that about 60% of emissions occur in the Northern Hemisphere (IPCC 2001)].

Table 7-1 illustrates the contribution of natural and anthropogenic sources at a global scale. Anthropogenic emission levels are lower than natural sources but result in an imbalance in the earth's nitrogen cycle, resulting in a rapid increase in atmospheric nitrous oxide concentrations.

Table 7-1 Estimated Emissions (in Teragrams – N per year) for N_2O Sources

Source Origin	Source Description	Estimated Emissions	Uncertainties
Natural	Natural Soils	6	3.3--9.7
	Ocean	3	1--5
Anthropogenic	Cultivated Soils	3.5	1.8--5.3
	Biomass Burning	0.5	0.2--1
	Industrial Sources	1.3	0.7--1.8
Other Minor Sources		0.4	0.2--0.5
Total		14.7	10--17

Source: IPCC 2001, IPCC 1996

N_2O emissions from soil occur through the nitrification and denitrification of nitrogen in soils. Nitrification is a process of biological oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) and nitrate (NO_3^-). This process plays a significant role in the nitrogen cycle because it provides nutrients for denitrifying bacteria and affects the overall reduction rate of nitrate in the denitrification process. Denitrification is the reduction process of nitrate to form nitrous oxide and molecular nitrogen. Production of N_2O and N_2 by microbial denitrification occurs when bacteria capable of denitrification colonize a location where oxygen is essentially absent and water, nitrate and decomposed organic compounds are present (Liu, 1996).

The following are some of the main factors that influence the emission of nitrous oxide from soil (IPCC, 1996).

- Soil water content, which regulates the oxygen supply.
- Temperature, which influences microbial activity.
- Soil nitrate or ammonium concentration.
- Available organic carbon (denitrifying bacteria require a usable organic carbon source, and microbial respiration of organic carbon may also regulate soil oxygen supply).
- Soil acidity, which controls both nitrification and denitrification and the nitrous oxide/nitrogen ratio in denitrification processes.

As indicated by the global inventory, soil is the main source of natural emissions. For this reason, this section deals with natural emissions from native soil in California.

Table 7-2 presents the first statewide annual model estimates for annual N_2O emissions from native soil sources in California. Cropland emissions do not include trace gas emissions sources from fertilizer usage of any kind. Emissions from fertilizer use are considered anthropogenic emissions and are reported in the Agriculture Chapter of this Inventory. These estimates were generated using the Cal-CASA model (Potter 1998, Potter 2000). This model was adapted from an early version of the Ames-CASA model to estimate ammonia (NH_3) emissions in California as part of a project funded by the California Air Resources Board though a contract with the National Aeronautics and Space Administration and Fresno State University.

Table 7-2
California's Estimated Emissions from Soils
(Gigagrams – N per year) of N_2O from Native Soils

Type	Emission	Total Area (ha)
Evergreen Needleleaf Forest	2.28	12,435,200
Mixed Forest	0.03	262,400
Woodlands/Wooded Grasslands	1.09	6,656,000
Grassland	0.27	1,952,000
Bare Soil	0	710,400
Cropland	2.14	8,505,600
Deciduous Broadleaf Forest	0.01	96,000
Open Shrubland	0.12	9,491,200
Total	5.94	40,108,800

Source: Potter 2001

The total natural N_2O emissions of 5.94 Gg-N (1.67 MMT CO_2 Eq.) are about 14 times smaller than the total statewide anthropogenic emissions of 23.55 MMT CO_2 Eq., reported previously in chapter 1of this report.

Methane

Methane's globally averaged atmospheric concentration in 1998 was 1,745 parts per billion (ppb). Pre-industrial methane concentrations determined from the Law Dome "DE08" Antarctic Ice Core have been measured at 848 ppb. Northern Hemisphere abundances average about 5% higher than those in the Southern Hemisphere (IPCC 2001)

Table 7-3 lists the most important natural and anthropogenic global sources of methane. Although the major source terms of atmospheric CH_4 have probably been identified, many of the source strengths are still uncertain due to the difficulty in assessing the global emission rates of the biospheric sources, whose strengths are highly variable in space and time (*IPCC, 2001*). The emissions from the various sources add up to a global total of about 500 Tg/yr, of which about 60% are related to human activities, such as agriculture, fossil fuel use and waste disposal. (IPCC, 2001)

Table 7-3 Estimated Global Emissions
(Teragrams CH$_4$ per year) for CH$_4$

Source Origin	Source Description	Estimated Emissions	Uncertainties
Natural	Wetlands	115	55--150
	Termites	20	10--50
	Oceans	10	5--50
	Other Natural Sources	15	10--40
Anthropogenic	Fossil Fuel Related	100	70--120
	Enteric Fermentation	85	65--100
	Rice Paddies	60	20--100
	Biomass Burning	40	20--80
	Landfills	40	20--80
	Animal Waste	25	20--30
	Domestic Sewage	25	20--30
	Total	**535**	**410 - 660**

Source: IPCC 2001

As seen in Table 7-3 wetlands are the primary producers of natural methane emissions in the world, contributing almost 72% of natural emissions. However, estimates of global methane fluxes from wetlands suggest that methane emissions from temperate-zone wetlands are small proportion of the total--typically between 5 and 10 million metric tons of methane per year worldwide (including U.S. wetlands)--when compared with estimated global wetlands emissions of 110 million metric tons (*Mathews 1987)*.   This being the case, California's wetlands, on average, should emit less methane than the global average. One survey of experiments conducted in the United States found estimates ranging from a negative flux (methane absorption) to a flux of 213 grams of methane per square meter per year, largely dependent on habitat type (*Mathews and Fung 1993)*. California has about 454,000 acres of nonagricultural wetlands [Bertoldi, 1996]. Using the highest reported emission factor of 213 g/m^2 year, California's wetlands would produce about 0.39 Tg yr^{-1} CH$_4$ (8.19 MMT CO$_2$ Eq.).   These worst-case natural methane emissions are about 5 times smaller than the average 2 Tg/year of methane emissions from anthropogenic sources produced in the 1990 to 1999 period and reported in chapter 1 .

Comparison of California Emissions with other States and Nations

This section compares carbon dioxide emissions from the combustion of fossil fuels because this is the dominant GHG.

California and the other States

As seen in Figure 7-2, California's anthropogenic emissions from the combustion of fossil fuels are larger on an absolute basis than most other states. Only Texas emits more than California.

Figure 7-2
CO_2 Emissions from the Combustion of Fossil Fuels: 1997
States with the lowest and highest Emissions
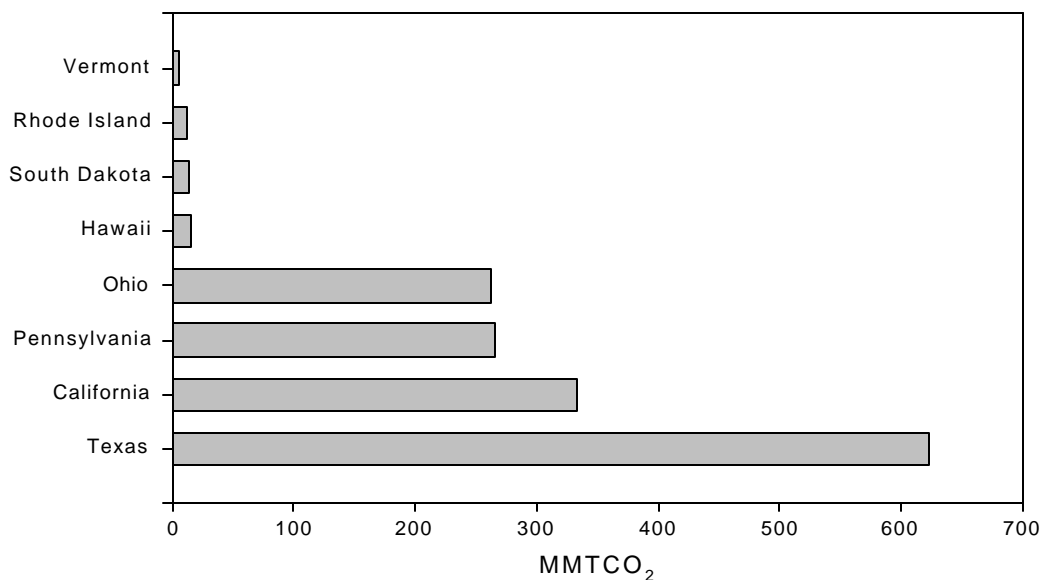
Source: EPA, 2001

Carbon dioxide emissions on an absolute basis, however, are not an adequate metric to compare the carbon intensity of the state economies. Absolute emissions are heavily influenced by the size of the economy and the state population. Figure 7-3 presents a graph showing carbon dioxide emissions from the combustion of fossil fuels on a per capita basis and per gross state product (GSP) basis. As can be seen in this figure, the California economy compares favorably with other states. Both on a per capita basis and per GSP, California emissions are one of the lowest in the nation.

Figure 7-3
CO$_2$ Emissions from the Combustion of Fossil Fuels: 1997
Emissions per Capita and per GSP for
States with the Lowest and Highest Absolute Emissions
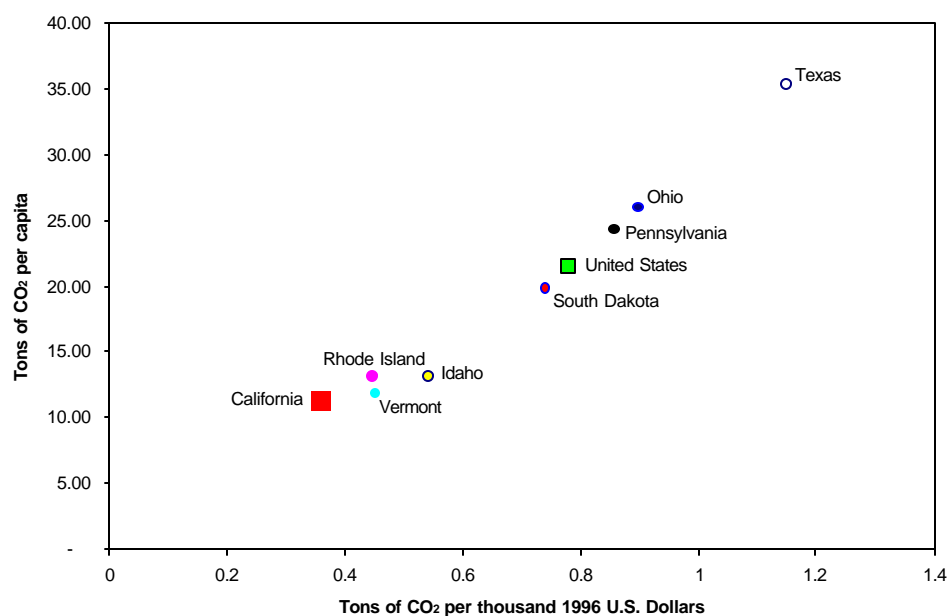
It is important to realize, however, that carbon dioxide emissions are also dependent on climatic factors, the state industrial composition, and other factors. A major influence on per capita and per GSP carbon dioxide emissions is energy efficiency.

- The Energy Information Administration (EIA) recently completed a survey of energy consumption in the residential sector in the USA (EIA 1999). The survey provides detailed energy consumption data for the four most populated states: California, Texas, New York, and Florida. Table 7-4 shows consumption normalized for climate conditions. The normalization is made by dividing the amount of energy consumed per square foot by the number of heating degree-days (HDD) and cooling degree-days for heating and cooling requirements, respectively. The California residential sector is more efficient than the U.S. as a whole. The only exception is the space-heating intensity with natural gas.

Table 7-4
Energy Intensity in the Residential Sector

	U.S.	New York	California	Texas	Florida
Air-Conditioning (AC) Intensity	KWh/(CDD x CSF/1000)				
Electric AC	0.80	0.61	0.59	0.96	0.71
Central AC	0.74	0.63	0.58	0.93	0.70
Room/Wall AC	0.91	0.70	0.77	1.17	0.82
Space-Heating Intensity	Physical Unit/(HDD x HSF/1000)				
Electricity (KWh)	0.794	0.565	0.618	1.009	1.114
Natural Gas (cubic feet)	7.876	7.311	9.095	10.458	7.587
Notes: CDD = Cooling Degree-Days; CSF = Cooled Square Footage; HDD = Heating Degree-Days; HSF = Heated Square Footage Source: EIA, 1999					

- Energy-intensive manufacturing represents approximately 10 percent of the total economic output in California, compared to about 22 percent for the U.S. as a whole. However, when comparing within individual industry categories, manufacturing energy intensity (measured as the ratio of energy consumed to value added) is lower in California than for the U.S. as a whole (Schipper 1995).

- In the transportation sector the data shows that per capita fuel use for cars and light trucks is slightly lower in California than for the nation as a whole. This goes against the common belief that Californians consume more fuel for personal transport than most other states (Schipper 1995).

- Energy consumption and carbon dioxide emissions per capita are about 30 and 40 percent lower in California than in the U.S. as a whole, respectively. The difference is explained by the higher reliance on natural gas (lower carbon dioxide emissions per unit of heat generated during combustion), more cogeneration units, and the use of renewable (e.g. wind, biomass) sources of electricity production. Using a decomposition analysis, researchers at Lawrence Livermore National Laboratory concluded that the differences in climate and types of industry explain two-thirds of the lower energy consumption per capita in California as compared to the United States as a whole. The balance or one-third of the total is due to lower energy intensities that are the result, in part, of higher energy efficiency appliance and building standards in California (Schipper, 1995).

California in the International Arena

Figure 7-4 presents the carbon dioxide emissions from the combustion of fossil fuels per capita and per GSP or gross domestic product (GDP) for California and representative countries. On this basis, it is clear that California's emissions are lower than some of the major industrialized countries and comparable with emission levels from some European countries.

Figure 7-4
CO_2 Emission Intensities for California and Selected Countries
**Fossil Fuel Combustion: 1995**
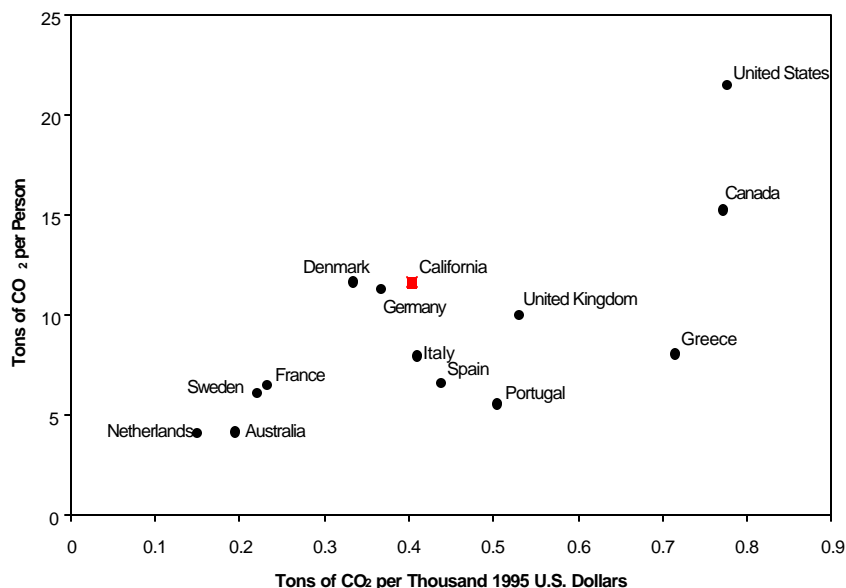
Impacts of Past Energy and Air Quality Standards, Regulations, and Policies

As seen in Figure 7-5 in-state CO_2 emissions have not increased since reaching peak levels in the mid-1970s. This is a remarkable achievement considering that the U.S. increased its emissions by about 20 percent during the same period and considering that the state economy and the population grew by 281 and 65 percent, respectively.

Figure 7-5

Historical CO_2 Emissions for California
From the Combustion of Fossil Fuels: 1970-1999
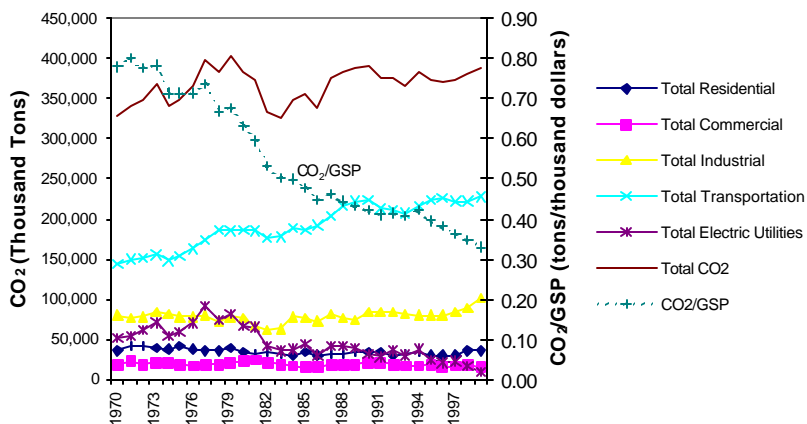
It is extremely difficult to quantify the effect of past air quality and energy standards, regulations, and policies on recent GHG emissions. At a macro level, it can be easily seen from figure 7-6 that there have been significant changes in the carbon intensity of the California economy. This figure shows the "experience curve" of the state economy with respect to carbon dioxide emissions. Experience curves are used to demonstrate the effect of accumulated knowledge or level of activity on the price or emission characteristics of technologies. It is well known that experience improves performance and reduce prices. This effect has been only relatively recently considered in the climate change mitigation arena. The y-axis is the amount of CO_2 emitted per unit of GSP. The x-axis is the cumulative GSP since 1950. For example, the CO_2/GSP in 1990 was 0.42 and the corresponding cumulative GSP from 1950 to 1990 was about $19,000 billion in constant 1996 dollars. The scales for both axes are logarithmic. This figure demonstrates that California has been making significant progress reducing its carbon dioxide emissions per GSP.

The first line in Figure 7-6 represents the data from 1970 to 1979. The second line, which is below the first one, contains data from 1980 to 1984, and the lower line, data from 1985 to 1999. This figure shows a shift in generation patterns in California. The second line represents a drastic departure from the business- as-usual trend in emissions through 1979. This was mostly due to the switch from residual fuel oil to natural gas in in-state power plants. The slope of the third line shows that reductions in emissions per GSP are at a faster rate than in the period from 1970 to 1979, but at a lower pace than rate of reduction of CO_2 emissions per GSP during 1979 to 1984.

Figure 7-6
Carbon Intensity of the California Economy
Experience Curve from 1970 to 1999
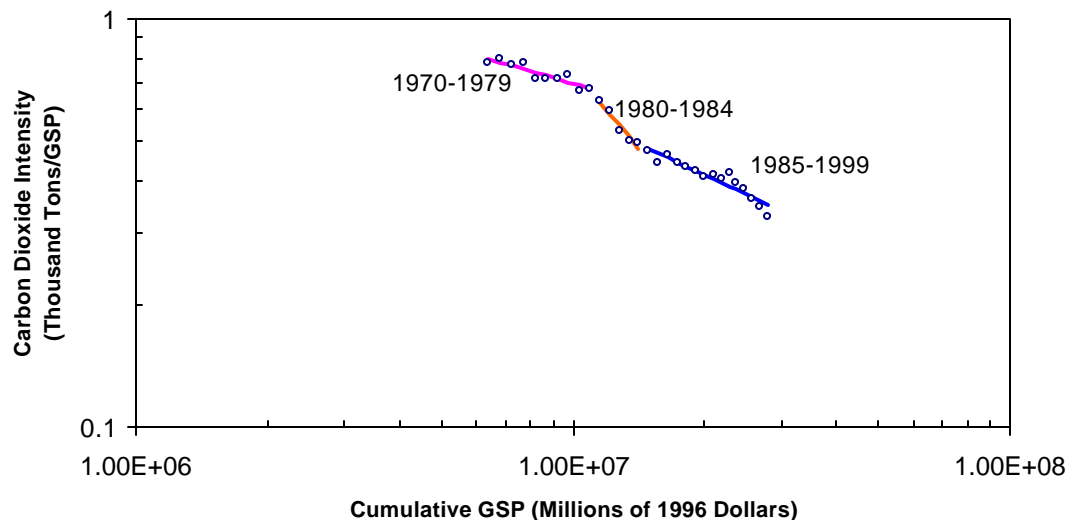
How did past air quality and energy standards, regulations, and policies contribute to the observed behavior demonstrated in Figures 7-5 and 7-6? The following paragraphs address this issue.

Energy Standards, Regulations, and Policies

In California, the Air Resources Board and the local air districts are in charge of developing and implementing air quality management plans to improve air quality in California to a level required to comply with both state and national ambient air quality standards. The California Energy Commission is an energy-planning agency. This agency is also in charge of the adoption of energy efficiency standards for appliances and buildings. Both the California Public Utilities Commissions and the California Energy Commission were instrumental in the implementation of past programs designed to increase the penetration of cogeneration and renewable resources in the electricity generation sector.

The California Energy Commission conducted a retrospective analysis of the impact of past efficiency measures on in-state energy consumption (CEC 1999)(CEC 2001a). These energy savings can be converted into carbon dioxide emissions avoided as shown in Table 7-5. The CO_2 reductions shown in this table assume that a natural gas burning power plant with a heat rate of 10,000 Btu/KWh would have been the marginal power plant producing the avoided energy consumption.

Increased use of Cogeneration and Renewables

Cogeneration is the simultaneous production and use of electricity and useful heat. For example, in an industrial complex a cogeneration power plant may use a gas turbine to generate electricity and the flue gases from the gas turbine are then fed to a boiler to generate steam, which is used in the manufacturing process. Cogeneration is much more efficient than the separate systems that its replaces: one to generate electricity and the other to produce useful heat.

The Public Utility Regulatory Policies Act of 1978 (PURPA) encouraged non-utilities to begin producing power by exempting them from previous legislative restrictions. Most of the non-utilities consist of "qualifying facilities." Qualifying facilities were non-utilities that generate electricity using cogeneration power plants or that used renewable energy as a fuel source. PURPA required utilities to purchase all electricity offered for sale by these non-utility generators.

Late in the 1980's, the California Legislature passed a tax incentive law encouraging new facilities to use renewable sources. California production by solar, wind, and geothermal resources by non-utilities totaled almost 87 percent of the nation's total non-utility production from these sources.

Non-utility generators in California and Texas produced about 53 and 49 billion Kilowatthours in 1991, respectively. This represented about 41 percent of the nation's non-utility electricity production. By establishing standard contracts, the California Public Utilities Commission was instrumental in the development of non-utility generation in California.

To estimate the impact of higher penetration of cogeneration and renewables presented in Table 7-5, the following assumptions were made: 1) 1998 is a representative year for the period of interest; 2) the amount of useful heat produced by cogenerators in 1998 would have been produced in separate boilers; 3) these boilers would have an

average thermal efficiency of 90 percent; and, 4) these boilers would have used natural gas. The amount of useful heat for 1998 was retrieved from the E-GRID2000 database (EPA 2001).

Air Quality Regulations Limiting NO_x Emissions from Power Plants

Power plants switched from residual fuel oil to natural gas mostly in the 1976 to 1982 period. This may have been due mostly to economic conditions favoring natural gas over residual fuel oil. After 1990, however, residual fuel oil has been less expensive than natural gas in California (EIA 2001). In theory, utility boilers could have opted to switch to natural gas. This did not happen, in part due to the existing air quality regulations, which have imposed very stringent maximum nitrogen oxide (NO_x) emission levels from existing power plants. Utility boilers cannot comply with these limits burning residual fuel oil. In fact using this fuel may damage the control equipment installed to reduce NO_x emissions. Some air quality regulations also explicitly allow burning of fuels other than natural gas only if there is a natural gas curtailment situation.

Data from E-GRID2000 for 1998 was used to roughly estimate the increase of CO_2 emissions that would have been released to the atmosphere. This was done by estimating the increase in carbon dioxide emissions that would have occurred if utility boilers had burned residual fuel oil instead of natural gas. The historical 1998 heat input to the boilers was assumed to be the same. These boilers burned residual fuel oil in the 1970s.

Table 7-5
Impact of Air Quality and Energy Consideration
On GHG Emission in California: Average for 1990-1999

	Emission Reductions (MMT CO_2)
Electricity Savings	
Appliances Standards	3
Building Standards	3
Conservation & Energy Efficiency	
Electric Utilities	8
Public Agencies	1
Natural Gas Savings	
Agricultural & Water Pumping	0.13
Commercial	1.29
Industrial	1.61
Residential	4.17
Sub-total	22.2
PURPA	
Cogeneration	31
Renewable Resources	7.4
Sub-total	38.5
Switch to Natural Gas in Utility Boilers	9
Total	69.7

The average CO_2 emission from the combustion of fossil fuels from 1990 to 1999 was about 345 MMT CO_2. According to Table 7-5, without the energy efficiency programs and the strong implementation of PURPA in California, the in-state emissions would have been about 20 percent higher in the 1990s.

Impact of Out-State Power Plants Serving California

From 1990 to 1999, California imported about 72,000 million KWh per year. This amount has been relatively constant since 1983 (CEC 2001b). If this power had been generated in California, the amount of CO_2 released to the atmosphere would have been about 38.3 MMT CO_2. This is estimated assuming that the hypothetical power plants burn natural gas and have a heat rate of 10,000 Btu/KWh. This represents about 11 percent of the average annual CO_2 emissions from the combustion of fossil fuels in California. If we use the average CO_2 emissions for 1998 reported by U.S. EPA in E-GRID2000 of 478 lb/MWh (EPA 2001) the increase of emissions would have been about 5 percent. This is because E-GRID considers only the CO_2 emissions that should be attributed to electricity production in cogeneration power plants. Cogeneration power plants produce both electricity and useful heat; therefore, it is more equitable to apportion the CO_2 emissions from the combustion of fossil fuels from these plants between electricity and thermal energy. This consideration makes a significant difference in California because, as indicate before, cogeneration represents about 23 percent of the in-state generation.

Conclusions

Anthropogenic emissions result in an imbalance in the nitrogen and carbon cycle in the earth and have resulted in increased nitrous oxide and methane concentrations. In California, anthropogenic sources of both nitrous oxide and methane seem to emit more than natural sources. Long-term net changes of carbon in California lands are due to human activities.

Carbon dioxide emissions in California have remained at about the same levels since the mid-1970s. Air quality and energy standards, regulations, and policies explain this trend. Without them emissions in the 1990s would have been about 20 percent higher. On the other hand, if in-state sources had provided the energy generated by out-of-state power plants serving California, emissions in the 1990s would have been from 5 to 11 percent higher than their historical levels. Under this scenario, in-state emissions would have remained almost at the same level from 1990 to 1999 because the amount of net electricity imports has remained almost unchanged since 1983.

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